PB87-166526

Evaluation of Flexible Membrane Liner Seams After Chemical Exposure and Simulated Weathering

Bureau of Reclamation, Denver, CO

Prepared for

Environmental Protection Agency, Cincinnati, OH

Feb 87

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA/600/2-87/015

2.

3. RECIPIENT'S ACCESSION NO.
PB87 166526/AS

4. TITLE AND SUBTITLE
EVALUATION OF FLEXIBLE MEMBRANE LINER SEAMS AFTER CHEMICAL EXPOSURE AND SIMULATED WEATHERING

5. REPORT DATE
February 1987

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
W.R. Morrison and L.D. Parkhill

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Bureau of Reclamation
Engineering and Research Center
Denver, CO 80225

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
EPA-IAG-DW14930547

12. SPONSORING AGENCY NAME AND ADDRESS
Hazardous Waste Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Strength and durability were tested in presently available seaming systems for FML's (flexible membrane liners). The seams were exposed to selected, simulated environmental conditions over short periods of up to 52 weeks. A total of 37 combinations of supported and unsupported polymeric sheet materials joined by various seaming methods was subjected to 6 chemical solutions, brine and water immersion, freeze/thaw cycling, wet/dry cycling, heat aging, and accelerated outdoor aging. Effects of these environmental conditions were evaluated using shear and peel strength tests before and after exposure. The tests were performed under dynamic load at room temperature and under static dead load at 50°C. In addition, several NDT (nondestructive test) methods were evaluated.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
Release to Public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
297

22. PRICE

PB87-166526

EPA/600/2-87/015
February 1987

EVALUATION OF FLEXIBLE MEMBRANE LINER SEAMS AFTER CHEMICAL EXPOSURE AND SIMULATED WEATHERING

by

W. R. Morrison and L. D. Parkhill
Bureau of Reclamation
Engineering and Research Center
Denver, Colorado, 80225

Interagency Agreement No. DW 14930547-01-2

Project Officer

Mary Ann Curran
Land Pollution Control Division
Hazardous Waste Engineering Research Laboratory
Cincinnati, Ohio 45268

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement number DW 14930547-01-2 to the U.S. Bureau of Reclamation. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous waste. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the EPA; the permitting and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report evaluates flexible membrane liner seams exposed to selected, simulated environmental conditions over short periods. The document will be useful to liner manufacturers and fabricators, designers, specifiers, and quality assurance engineers involved in hazardous waste disposal facilities.

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering Research Laboratory

ABSTRACT

Strength and durability were tested in presently available seaming systems for FML's (flexible membrane liners). The seams were exposed to selected, simulated environmental conditions over short periods of up to 52 weeks. A total of 37 combinations of supported and unsupported polymeric sheet materials joined by various seaming methods were subjected to six chemical solutions, brine and water immersion, freeze/thaw cycling, wet/dry cycling, heat aging, and accelerated outdoor aging. Effects of these environmental conditions were evaluated using shear and peel strength tests before and after exposure. The tests were performed under dynamic load at room temperature and under static dead load at 50 °C. In addition, several NDT (nondestructive test) methods were evaluated.

This report was submitted in fulfillment of Contract No. DW14930547-01-2 by the U.S. Bureau of Reclamation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period January 1983 to December 1985, and work was completed as of December 1985.

CONTENTS

Notice ii
Foreword iii
Abstract iv
Figures vii
Tables xiv
Abbreviations and symbols xv
Acknowledgments xvi

1. Introduction 1
    Background 1
    Scope of work 1
2. Conclusions and recommendations 5
3. Guidelines for factory and field seaming of flexible membrane liners 16
4. Summary of literature search 21
    USBR Literature Survey 21
    Interagency Technology Transfer Meeting 21
    Geotechnical Conferences 22
5. Seaming methods 24
    General 24
    Liquid-applied solvent or adhesive systems 25
    Thermal methods 25
    Extrusion welding methods 27
    Vulcanizing tapes and adhesives 27
    Tapes and mechanical seaming 28
6. Laboratory test program 31
    Liner materials evaluated 31
    Field seams 31
    Chemical immersion 32
    Exposure methods 33
    Test methods 34
    Nondestructive seam testing 35
    Quality assurance program 38
7. Test results and discussion 67
    Shear and peel tests 67
    Dead load testing 69
    EMMAQUA testing 70
    Weight and thickness measurements 70
8. Performance of seams 187
    General 187
    Sample 1 187
    Sample 2 188
    Sample 3 188

CONTENTS - Continued

Sample 4 188
Sample 5 189
Sample 6 189
Sample 7 190
Sample 8 190
Sample 9 190
Sample 10 191
Sample 11 191
Sample 12 191
Sample 13 192
Sample 14 192
Sample 15 192
Sample 16 192
Sample 17 193
Sample 18 193
Sample 19 193
Sample 20 194
Sample 21 194
Sample 22 194
Sample 23 195
Sample 24 195
Sample 25 195
Sample 26 195
Sample 27 195
Sample 28 196
Sample 29 196
Sample 30 196
Sample 31 196
Sample 32 196
Sample 33 197
Sample 34 197
Sample 35 197
Sample 36 197
Sample 37 197

References 199
Appendix. Seam and Peel Strength Test Results 202
Chemical Immersion Photographs 202

FIGURES

Number Page

1. View of test specimen used to determine shear strength of supported flexible membrane liner seams 19
2. View of dynamic shear test 20
3. View of factory seam samples 5, 7 and 8 43
4. View of factory seam samples 9 and 10 44
5. View of factory seam samples 14 and 15 45
6. View of factory seam sample 6 and field seam sample 22 46
7. View of factory seam sample 13 and field seam sample 30 47
8. View of field seam samples 32 and 33 48
9. Typical procedures for making adhesive field seams 49
10. Fillet welding of HDPE liner 51
11. View of immersion samples 52
12. EMMAQUA testing machines for accelerated outdoor exposure 53
13. View of dynamic peel test 54
14. Static dead load test apparatus 55
15. Failure mode 2 56
16. Failure mode 3 57
17. Failure mode 4 58
18. Failure mode 5 59

19. Failure mode 6 60

20. Failure mode 7 61

21. Failure mode 8 62

22. Sketches of a typical pulse/echo instrument display . 63

23. View of UPE technique for testing FML seam 64

24. View of surface transducer used in UIP technique . . 64

25. Calibrated UIP instrument display 65

26. Air lance testing of FML seams 65

27. Vacuum testing of FML seams 66

28. Closeup view of vacuum testing of FML seams 66

29. Seam shear strength - thermal hot air factory seam - 36 mil CPE(S) - sample 1 91

30. Seam peel strength - sample 1 92

31. Seam shear strength - thermal hot air factory seam - 36 mil CPE(S) - sample 2 93

32. Seam peel strength - sample 2 94

33. Seam shear strength - thermal hot air factory seam - 30 mil CSPE(S) - sample 3 95

34. Seam peel strength - sample 3 96

35. Seam shear strength - thermal hot air factory seam - 36 mil CPE(S) - sample 4 97

36. Seam peel strength - sample 4 98

37. Seam shear strength - thermal hot air factory seam - 36 mil CSPE(S) - sample 5 99

38. Seam peel strength - sample 5 100

39. Seam shear strength - thermal hot air factory seam - 36 mil CSPE(S) - sample 6 101

40. Seam peel strength - sample 6 102

41. Seam shear strength - solvent adhesive factory seam - 36 mil CSPE(S) - sample 7 103

42. Seam peel strength - sample 7 104

43. Seam shear strength - thermal dielectric factory seam - 36 mil CSPE(S) - sample 8 105

44. Seam peel strength - sample 8 106

45. Seam shear strength - thermal hot air factory seam - 38 mil EIA(S) - sample 9 107

46. Seam peel strength - sample 9 108

47. Seam shear strength - vulcanized factory seam - 40 mil EPDM(S) - sample 10 109

48. Seam peel strength - sample 10 110

49. Seam shear strength - solvent adhesive factory seam - 30 mil CPE(U) - sample 11 111

50. Seam peel strength - sample 11 112

51. Seam shear strength - thermal dielectric factory seam - 30 mil CPE(U) - sample 12 113

52. Seam peel strength - sample 12 114

53. Seam shear strength - thermal hot wedge factory seam - 30 mil LLDPE - sample 13 115

54. Seam peel strength - sample 13 116

55. Seam shear strength - solvent adhesive factory seam - 30 mil PVC(U) - sample 14 117

56. Seam peel strength - sample 14 118

57. Seam shear strength - dielectric factory seam - 30 mil PVC(U) - sample 15 119

58. Seam peel strength - sample 15 120

59. Seam shear strength - thermal dielectric factory seam - 30 mil PVC/CPE(U) - sample 16 . . . 121

60. Seam peel strength - sample 16 122

61. Seam shear strength - bodied solvent adhesive field seam - 36 mil CPE(S) - sample 17 123

62. Seam peel strength - sample 17 124

63. Seam shear strength - solvent adhesive field seam - 36 mil CPE(S) - sample 18 125

64. Seam peel strength - sample 18 126

65. Seam shear strength - bodied solvent adhesive field seam - 36 mil CSPE(S) - sample 19 127

66. Seam peel strength - sample 19 128

67. Seam shear strength - bodied solvent adhesive field seam - 36 mil CSPE(S) - sample 20 129

68. Seam peel strength - sample 20 130

69. Seam shear strength - adhesive field seams - 36 mil CSPE(S) - sample 21 131

70. Seam peel strength - sample 21 132

71. Seam shear strength - bodied solvent adhesive field seam - 36 mil CSPE(S) - sample 22 133

72. Seam peel strength - sample 22 134

73. Seam shear strength - solvent adhesive field seam - 36 mil CSPE(S) - sample 23 135

74. Seam peel strength - sample 23 136

75. Seam shear strength - solvent adhesive field seam - 36 mil CSPE(S) - sample 24 137

76. Seam peel strength - sample 24 138

77. Seam shear strength - solvent adhesive field seam - 36 mil CSPE(S) - sample 25 139

78. Seam peel strength - sample 25 140

79. Seam shear strength - thermal hot air field seam - 38 mil EIA(S) - sample 26 141

80. Seam peel strength - sample 26 142

81. Seam shear strength - gumtape cement field seam - 40 mil EPDM(S) - sample 27 143

82. Seam peel strength - sample 27 144

83. Seam shear strength - solvent adhesive field seam - 30 mil CPE(U) - sample 28 145

84. Seam peel strength - sample 28 146

85. Seam shear strength - solvent adhesive field seam - 30 mil CPE(U) - sample 29 147

86. Seam peel strength - sample 29 148

87. Seam shear strength - extrusion fillet weld field seam - 30 mil HDPE(U) - sample 30 149

88. Seam peel strength - sample 30 150

89. Seam shear strength - extrusion fillet weld field seam - 80 mil HDPE(U) - sample 31 151

90. Seam peel strength - sample 31 152

91. Seam shear strength - extrusion lap weld field seam - 80 mil HDPE(U) - sample 32 153

92. Seam peel strength - sample 32 154

93. Seam shear strength - thermal hot dual wedge field seam - 80 mil HDPE(U) - sample 33 155

94. Seam peel strength - sample 33 156

95. Seam shear strength - thermal hot wedge field seam - 30 mil LLDPE(U) - sample 34 157

96. Seam peel strength - sample 34 158

97. Seam shear strength - solvent adhesive field seam - 30 mil PVC(U) - sample 35 159

98. Seam peel strength - sample 35 160

99. Seam shear strength - solvent adhesive field seam - 30 mil PVC(U) - sample 36 161

100. Seam peel strength - sample 36 162

101. Seam shear strength - solvent adhesive field seam - 30 mil PVC(S) - sample 37 163

102. Seam peel strength - sample 37 164

103. Results of 1-year EMMAQUA exposure for 30 mil - HDPE field seam (sample 34). Sample had melted at two areas 165

104. Percent weight change - 36 mil CPE(S) - sample A . . 166

105. Percent weight change - 36 mil CPE(S) - sample B . . 167

106. Percent weight change - 30 mil CSPE(S) - sample C . . 168

107. Percent weight change - 36 mil CSPE(S) - sample D . . 169

108. Percent weight change - 36 mil CSPE(S) - sample E . . 170

109. Percent weight change - 36 mil CSPE(S) - sample F . . 171

110. Percent weight change - 36 mil CSPE(S) - sample G . . 172

111. Percent weight change - 36 mil CSPE(S) - sample H . . 173

112. Percent weight change - 30 mil CSPE(S) - sample I . . 174

113. Percent weight change - 38 mil EIA(S) - sample J . . 175

114. Percent weight change - 40 mil EPDM(S) - sample K . . 176

115. Percent weight change - 30 mil CPE(S) - sample L . . 177

116. Percent weight change - 30 mil CPE(U) - sample M . . 178

117. Percent weight change - 36 mil HDPE(U) - sample N . . 179

118. Percent weight change - 80 mil HDPE(U) - sample O . . 180

119. Percent weight change - 80 mil HDPE(U) - sample P . . 181

120. Percent weight change - 80 mil HDPE(U) - sample Q . . 182

121. Percent weight change - 30 mil LLDPE(U) - sample R . 183

122. Percent weight change - 36 mil PVC(U) - sample S . . 184

123. Percent weight change - 30 mil PVC(U) - sample T . . 185

124. Percent weight change - 30 mil PVC(U) - sample U . . 186

125. Comparison of factory seaming methods for PVC . . . 198

TABLES

Number		Page
1.	Type of factory seams evaluated	3
2.	Types of field seams evaluated	4
3.	Performance of flexible membrane liner seams exposed to various chemicals	10
4.	Performance of flexible membrane liner seams exposed to water, brine, freeze/thaw cycling, wet/dry cycling and heat aging	13
5.	Matrix of FML research versus agency involvement, April 1983	23
6.	Adhesive-type seaming methods for flexible membrane linings	29
7.	Thermal and mechanical seaming methods for flexible membrane linings	30
8.	Samples for weight and thickness determinations	40
9.	Description of failure modes	41
10.	Recommended NDT methods based on this research	42
11.	Key to symbols for figures 12 to 102	72
12.	Comparison of factoring seaming methods for supported 36-mil CSPE (10 by 10 polyester scrim) liners	73
13.	Comparison of factoring seaming methods for unsupported PVC and CPE liners	74
14.	Comparison of field seaming methods for 80-mil HDPE liners	75
15.	Results of dead load testing	76
16.	Results of visual inspection for EMMAQUA samples	78
17.	Percent change in weight after exposure	81
18.	Percent change in thickness after exposure	86

ABBREVIATIONS AND SYMBOLS

ASTM	American Society for Testing and Materials
B23	23 °C
B50	50 °C
CPE	Chlorinated polyethylene
CQA	Construction quality assurance
CSPE	Chlorosulfonated polyethylene
EIA	Ethylene interpolymer alloy
EMA	EMMAQUA
EMMAQUA	Equitorial mount with mirrors for acceleration plus water spray
EPDM	Ethylene propylene diene rubber
E&R	Engineering and Research
FML	Flexible membrane liner
F/T	Freeze/thaw
FUR	Furfural
HA	Heat aging
HCl	Hydrochloric acid
HDPE	High density polyethylene
H_2O	Water
HSWA	Hazardous and Solid Waste Amendments of 1984
LANL	Los Alamos National Laboratory
LLDPE	Linear low density polyethylene
MCL	Methylene chloride
MEK	Methyl ethyl ketone
NDT	Nondestructive testing
NOH	Sodium hydroxide
NSF	National Sanitation Foundation
PHE	Phenol
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
S	Supported
U	Unsupported
UIP	Ultrasonic impedance plane
UPE	Ultrasonic pulse echo
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USNRC	U.S. Nuclear Regulatory Commission
W/D	Wet/dry
WPRS	Water and Power Resources Service

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of the following Bureau of Reclamation personnel who participated in the study:

H. F. Adams
R. K. Frobel
C. B. Haverland
F. C. Heller
B. V. Jones
K. K. Karpoff
T. J. Leiker
L. Morehouse
G. J. Myers
J. J. Schaffer

The chemical immersion testing was conducted by:

Hauser Laboratories
5680 Central Avenue
Boulder, Colorado 80306

The accelerated outdoor exposure testing was performed by:

DSET Laboratories, Inc.
Box 1850
Black Canyon Stage 1
Phoenix, Arizona 85029

The following companies contributed to this study by supplying samples, information, and technical assistance:

Battelle Pacific Northwest Laboratories
Burke Industries, Inc.
Carlisle SynTec Systems
E.I. duPont deNemour, and Co.
Dynamit Nobel of America, Inc.
B.F. Goodrich Company
Gulf Seal Corporation
Gundle Linings Systems, Inc.
Palco Linings, Inc.
Pantasote, Inc.
Sarnafil (U.S), Inc.
Schlegel Lining Technology, Inc.
Seaman Corporation
Staff Industries, Inc.
Stevens Elastomeric and Plastics Products, Inc.
Watersaver Company, Inc.

SECTION 1

INTRODUCTION

Background

An important aspect of hazardous waste treatment, storage, and disposal is the prevention of surface- and ground-water contamination by fluids containing hazardous constituents. Over the last few years, FML's (flexible membrane liners) have increasingly been specified and used in the construction of hazardous waste containment facilities, such as landfills and surface impoundments.[1]

In November 1984, the RCRA (Resource Conservation and Recovery Act) was amended when the President signed into law the HSWA (Hazardous and Solid Waste Amendments of 1984) [2]. Among the provisions that went into effect on that date were minimum technological requirements for hazardous waste disposal facilities. Of particular interest to this study are the requirements for a double liner, a leachate collection system, and a CQA (construction quality assurance) program for installing the FML's. The new requirements allow either a double FML system or a combination of an FML and clay liner.

A considerable number of laboratory tests and pilot-scale studies have been conducted by various Government and private-sector (non-Government) groups to assess the effects of chemical waste products on the integrity of FML's. However, little has been done to assess the performance of the various types of seams used in joining the manufactured roll goods in the factory and the panels seamed in the field.

Scope of Work

To learn more about the strength and durability of presently available seaming systems, the USEPA (U.S. Environmental Protection Agency) has funded research with the USBR (U.S. Bureau of Reclamation) to evaluate FML seams exposed to selected, simulated environmental conditions over short periods of up to 52 weeks. A total of 37 combinations of supported and unsupported polymeric sheet materials, manufactured in 1983, joined by various seaming methods were subjected to 6 chemical solutions, brine and water immersion, freeze/thaw cycling, wet/dry cycling, heat aging, and accelerated outdoor aging. The seams evaluated are listed in tables 1 and 2. Due to budget limitation and time constraints, not all the seaming methods that were available in 1983 were evaluated.

---

[1] Numbers in brackets refer to references listed in the bibliography

Related chemical compatibility data are available for most materials from textbooks, research reports, and FML manufacturers. However, the information is quite general. For example, terms such as good, fair, and poor are often used to describe chemical resistance without specifying limits to these terms. Consequently, it was decided to subject all FML seams to the various chemical solutions. This provided an opportunity to determine the extent of adverse reaction and document the results. Such information may be useful in future forensic-type analyses of FML's.

NSF (National Sanitation Foundation) and Drexel University are also conducting chemical compatibility studies for EPA as a correlative to this project. The NSF study is concerned with changes in mechanical and physical properties of FML's resulting from chemical immersion.

Effects of the environmental conditions in the Bureau study were evaluated using shear and peel strength tests before and after exposure. The tests were performed under dynamic load at room temperature, and under static dead load at 50 °C (122 °F).

In addition to seam testing six NDT (nondestructive test) methods were evaluated in this study. The six NDT methods included:

- Acoustic method - ultrasonic pulse echo (5 to 15 MHz)
- Acoustic method - continuous wave resonant frequency (167 kHz)
- Air lance - 345 kPa (50 $\mathrm{lb/in}^2$)
- Vacuum chamber
- Double seam pressurization
- Mechanical point stress

The two acoustic methods were performed at the Bureau's facility with equipment and personnel supplied by Battelle Pacific Northwest Laboratories, Richland, Washington [3]. The remaining techniques were performed and evaluated by Bureau personnel.

Table 1. Types of factory seams evaluated

Sample No.	Manufacturer/ fabricator	Lining material	Scrim (reinforcing fabric)	Seaming Method	Seam width (in)
1	A/A	36-mil CPE	6 x 6 leno polyester	Thermal-hot air	2.25
2	H/H	36-mil CPE	10 x 10 polyester	Thermal-hot air	1.00
3	B/B	30-mil CSPE	8 x 8 polyester	Thermal-hot air	2.50
4	B/B	36-mil CSPE	6 x 6 polyester	Thermal-hot air	3.00
5	B/B	36-mil CSPE	10 x 10 polyester	Thermal-hot air	2.00
6	A/A	36-mil CSPE	6 x 6 leno polyester	Thermal-hot air	2.25
7	G/L	36-mil CSPE	10 x 10 polyester	Bodied solvent adhesive	3.00
8	G/M	36-mil CSPE	10 x 10 polyester	Thermal-dielectric	1.25
9	J/J	38-mil EIA	polyester	Thermal-hot air	2.00
10	C/C	40-mil EPDM	10 x 10 nylon	Vulcanized/3/4 in. capstrip	1.50
11	E/L	30-mil CPE	-	Solvent adhesive	1.00
12	E/M	30-mil CPE	-	Thermal-dielectric	0.75
13	B/B	30-mil LLDPE	-	Thermal-hot wedge	0.62
14	E/L	30-mil PVC	-	Solvent adhesive	1.00
15	E/M	30-mil PVC	-	Thermal-dielectric	0.75
16	E/M	30-mil PVC/CPE	-	Thermal-dielectric	0.75

Table 2. Types of field seams evaluated

Sample number	Manufacturer/ fabricator	Lining material	Scrim (reinforcing fabric)	Seaming method	Seam width, inches
17	A	36-mil CPE	6 x 6 leno polyester	Bodied solvent adhesive	3.00
18	H	36-mil CPE	10 x 10 polyester	Solvent adhesive	3.00
19	B	30-mil CSPE	8 x 8 polyester	Bodied solvent adhesive	4.50
20	B	36-mil CSPE	6 x 6 polyester	Bodied solvent adhesive	4.50
21	B	36-mil CSPE	10 x 10 polyester	Adhesive	3.00
22	A	36-mil CSPE	6 x 6 leno polyester	Bodied solvent adhesive	3.00
23	G/L	36-mil CSPE	10 x 10 polyester	Solvent adhesive	3.00
24	G/M	36-mil CSPE	10 x 10 polyester	Solvent adhesive	3.00
25	I	36-mil CSPE	10 x 10 polyester	Solvent adhesive	3.00
26	J	38-mil EIA	polyester	Thermal-hot air	2.00
27	C	40-mil EPDM	10 x 10 nylon	Gum tape/cement	6.50
28	E/L	30-mil CPE	-	Solvent adhesive	3.00
29	E/M	30-mil CPE	-	Solvent adhesive	3.50
30	D	30-mil HDPE	-	Extrusion fillet weld	N/A
31	D	80-mil HDPE	-	Extrusion fillet weld	N/A
32	F	80-mil HDPE	-	Extrusion lap weld	1.75
33	K	80-mil HDPE	-	Thermal-hot dual wedge	1.00
34	B	30-mil LLDPE	-	Thermal-hot wedge	0.63
35	E/L	30-mil PVC	-	Solvent adhesive	2.00
36	E/M	30-mil PVC	-	Solvent adhesive	3.50
37	I	30-mil PVC	-	Solvent adhesive	3.00

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

1. Results of the study indicate no direct correlation exists between the seam shear and seam peel strengths. For example, high shear strength does not guarantee high peel strength. The shear test appears to be more indicative of the strengths and weaknesses of the parent material, whereas the peel test is more a measure of the strengths and weaknesses of the seam bond.

It is concluded that peel strength of a seam is an important property that should be tested along with the shear strength to evaluate the quality of a seaming method or operation.

2. Results of dead load peel testing indicated that for the most part, no direct correlation exists between the results of this testing and the dynamic peel testing. This conclusion may be due to the fact that the same load was used in all tests, rather than a variable load depending on the strength of the particular liner. However, several seam samples that exhibited low peel strength did fail in the dead load tests. The results also demonstrated the susceptibility of the unsupported CPE (chlorinated polyethylene) seams, both factory and field, to creep failure at elevated temperatures. This failure was primarily due to a weakness in the parent material rather than the seam.

It is concluded that the dead load peel test, as conducted in this study, was not a valid procedure for evaluating the quality of a seaming method or operation.

It is recommended that the dead load peel test be conducted utilizing a certain percentage of the ultimate peel strength. This will require additional testing to establish realistic dead load test values for the various FML seams.

3. For supported FML's, the seam strength properties within the same generic group [CPE or CSPE (chlorosulfonated polyethylene) for example] varied depending on the particular FML chemical formulation and the type of scrim (reinforcing fabric).

It is concluded that generic-type material specifications are not sufficient to ensure satisfactory performance of FML's seams when used for hazardous waste containment applications.

It is recommended that the specifications for hazardous waste containment incorporate special provisions to ensure a specific FML formulation for chemical compatibility with the materials to be contained.

This will require pretesting of the FML's including seams with the proposed effluent/leachate to determine chemical compatability. Assurance of supplying a qualified FML for the work can be accomplished by requiring third-party verification of the FML formulation to protect proprietary rights or by chemical fingerprinting.

4. Results of chemical immersion tests indicate that changes in weight and thickness of the materials affected occur quite rapidly. Significant changes were noted in these physical properties after only 1 week of immersion. However, the changes in seam properties of some materials may occur more slowly. For example, the EIA (ethylene interpolymer alloy) seams performed satisfactorily for 6 months in MEK (methyl ethyl ketone) and FUR (furfural) but then were severely damaged at 12 months in both chemicals.

It is concluded that short-term chemical immersion tests of up to 6 months may not be of enough duration to determine the chemical compatibility of some FML seams.

It is recommended that the 120-day immersion period specified in EPA Test Method 9090, "Compatibility Test for Waste and Membrane Liner," be reviewed to ensure that it is of long enough duration to determine chemical compatibility.

5. With regard to chemical immersion, the performance of the FML seams was that essentially expected, based on the recommendations of the FML manufacturer and review of the available chemical compatibility data. The purpose of subjecting all seam samples to the various chemical solutions was to determine the extent of adverse reaction and document the results. Such information may be useful in future forensic-type analyses of FML's, as well as a correlative to the chemical compatibility studies being conducted for EPA by Drexel University and NSF.

It is concluded that existing published data and manufacturers' recommendations on chemical compatibility of FML materials give a reasonable basis to make an initial judgment on the expected performance of seams in a given chemical environment.

6. Results of the EMMAQUA (equatorial mount with mirrors for acceleration plus water spray) testing indicate that the 1-year exposure may be too long, resulting in accelerated weathering conditions

too severe for some materials. (The accelerated rate of degradation of the EMMAQUA exposure for FML's is approximately eight times as intense as that of conventional outdoor exposure.) Such a condition could produce erroneous results. For example, several polyolefin samples suffered severe thermal degradation from the EMMAQUA exposure. Over the years, the USBR has routinely conducted outdoor exposure tests on FML's and have never observed this type of thermal degradation. Based on the visual inspections, the thermal degradation occurred between 6 and 12 months of exposure. The NSF, in certifying new exposed FML's, requires both the parent material and the factory seam to pass a weathering test (EMMAQUA) of a minimum of 1 million langleys[2] (41,840 MJ/m^2) with a rating of 7 or better. The rating criteria are described in appendix A, part 9 of NSF Standard No. 54, "Flexible Membrane Liners" [4]. Under the EMMAQUA exposure, the 1 million langleys can be achieved in approximately 8 months. In this study, the samples during the 1-year period were exposed to about 1.45 million langleys.

It is concluded that the 1-year EMMAQUA exposure may be a too severe accelerated weathering condition for some FML materials and additional studies are recommended to determine if this method is truly representative of long-term weathering for FML's formulated for outdoor exposure.

7. Of the three thermal methods used to field seam HDPE liners, evaluated in this study, the extrusion lap weld produced the highest shear and peel strengths. The extrusion fillet weld produced a slightly higher shear strength than the hot dual wedge, but the peel strengths of these two seams were nearly identical. In the peel tests, however, the hot dual wedge seam exhibited a failure within the seam area, and the other two field seams failed at the seam edge.

It is concluded that of three methods used to field seam HDPE liners, the extrusion lap weld produces the highest shear and peel strengths.

ESC (environmental stress cracking) of the HDPE seams was not evaluated in this study since conventional immersion tests will not duplicate it. Resistance of HDPE materials to ESC is not only dependent on the type of PE resin, but also on the temperature history during manufacturing. Therefore, the seam may not have the same resistance to ESC as the rest of the membrane. Although NSF Standard No. 54 has a requirement concerning the ESC resistance of the parent HDPE material, there are no such provisions for the seams. Consequently, additional studies are recommended to develop a method for testing HDPE seams for ESC.

8. Of the two factory seaming methods used for the unsupported PVC (polyvinyl chloride) and CPE liners, the seams made with the solvent adhesive exhibited higher shear strengths, whereas those made dielectrically produced higher peel strength values. The higher

---

[2] A langley is a unit of solar radiation equivalent to 1 gram calorie per square centimeter of irradiated surface.

shear strength was primarily due to the wider factory seam for the solvent adhesive seam. In the shear tests, failure occurred in the parent material. The same was also true for the peel tests, except for the PVC solvent adhesive seam, where the failure occurred within the seam itself. No appreciable difference was noted in the performance of the two seaming methods however.

It is concluded that the two factory seaming methods evaluated in this study for PVC and CPE produced satisfactory seams. Although not widely used, it is recommended that studies be conducted on evaluating the thermal-hot air method for factory seaming PVC and CPE materials. This would provide an opportunity to document the results for future specification considerations.

9. As part of this study, the factory seam requirements listed in NSF Standard No. 54 were reviewed for the materials evaluated. Based on the results of this study, and other USBR studies, the shear requirements (breaking factor) are satisfactory, but the peel requirements (peel adhesion) for the unsupported materials such as CPE and PVC appear to be low. The current requirement is FTB (film tearing bond) or 10 lbf/in width. Results of this study indicate that industry is capable of producing factory seams with higher peel strengths. Consequently, it is recommended that the NSF Joint Committee on FML's give consideration to increasing the peel adhesion values for CPE and PVC.

The seam peel requirement for the supported CPE and CSPE materials is ply separation in the plane of the seam or 10 lbf/in width. In this study, however, ply separation only occurred with the CSPE materials that were reinforced with a 10 by 10 scrim. Consequently, the requirement of ply separation for materials manufactured with a more open scrim (6 by 6, 8 by 8, etc.) may not be applicable. Also, the peel adhesion requirement of 10 lbf/in width appears to be low. Consequently, it is recommended that consideration also be given to increasing the peel adhesion values for supported CPE and CSPE materials.

10. Results of studies on the NDT (nondestructive testing) methods indicate that each method has particular strengths and limitations as a check for seam bonding. However, none of the methods determine seam strengths.

It is concluded that the air lance, vacuum chamber, and mechanical point stressing work well on most seam types with the following limitations:

a. The air lance method was unsatisfactory on the stiffer HDPE materials and supported sheets greater than 45 mils in thickness.

b. Vacuum chamber testing should be limited to 30-mil and thicker liners because of the deformation experienced by the thinner materials under relatively low vacuum.

c. Mechanical point stressing should not be used on thinner liners susceptible to puncture.

For the two electronic methods evaluated, the UPE worked well on the unsupported seams (PVC and LLDPE). It was not effective on the fillet-welded HDPE seam since this seam does not have a flat, uniform surface required for the UPE technique. It also did not work on the supported seams due to interference in the reflection of the sound by the reinforcing scrim.

The UIP (ultrasonic impedance plane) technique also worked well on the unsupported seams (PVC and LLDPE). As with the UPE technique it does not work on the fillet-welded HDPE seams due to the non-uniform seam surface. For the supported seams, this technique worked on the CSPE reinforced with a 10 by 10 scrim, but not with these having a wider open scrim (6 by 6, 6 by 12). Neither electronic method was effective on the EIA seams.

11. The performance of the individual seams are summarized in table 3 for chemical immersion and in table 4 for the remaining exposure conditions. The performance is rated satisfactory, unsatisfactory or questionable indicating that additional testing is needed to determine suitability. For example, several CSPE materials exhibited a significant increase in shear strength after exposure to heat aging and/or brine exposure at 50 °C. Additional testing is required to determine what effect this type of exposure would have on the other physical properties such as tear strength, puncture resistance and dimensional stability.

Performance was considered unsatisfactory if there was over a 20 percent loss in either shear or peel strength after exposure, or if the particular exposure caused adverse effects such as stiffening, shrinkage or blistering of the material.

Table 3. Performance of flexible membrane liner seams exposed to various chemicals

Sample No.	Material	Phenol	HCl	NaOH	MEK	MCL	Furfural
1	36 mil CPE(S)	U	U	U	U	U	U
2	36 mil CPE(S)	U	U	U	U	U	U
3	30 mil CSPE(S)	U	S	U	S	U	S
4	36 mil CSPE(S)	U	S	U	U	U	U
5	36 mil CSPE(S)	U	Q	U	U	U	U
6	36 mil CSPE(S)	U	U	U	U	U	U
7	36 mil CSPE(S)	U	S	U	S	U	S
8	36 mil CSPE(S)	U	S	U	S	U	U
9	38 mil EIA(S)	U	S	U	U	U	U
10	30 mil EPDM(S)	S	S	U	S	S	S
11	30 mil CPE(U)	U	S	U	U	U	U
12	30 mil CPE(U)	U	S	U	U	U	U
13	30 mil LLDPE(U)	S	S	S	S	S	S
14	30 mil PVC(U)	U	S	U	U	U	U
15	30 mil PVC(U)	U	S	U	U	U	U
16	30 mil PVC/CPE(U)	U	U	U	U	U	U

Table 3. Performance of flexible membrane liner seams exposed to various chemicals (continued)

Sample No.	Material	Phenol	HCl	NaOH	MEK	MCL	Furfural
17	36 mil CPE(S)	U	U	U	U	U	U
18	36 mil CPE(S)	U	U	U	U	U	U
19	30 mil CSPE(S)	S	S	U	S	U	U
20	36 mil CSPE(S)	U	SU	U	U	U	U
21	36 mil CSPE(S)	U	Q	U	S	U	S
22	36 mil CSPE(S)	U	S	U	S	U	U
23	36 mil CSPE(S)	U	S	U	S	U	U
24	36 mil CSPE(S)	U	S	U	S	U	Q
25	36 mil CSPE(S)	U	U	U	S	U	S
26	38 mil EIA(S)	U	S	U	U	U	U
27	30 mil EPDM(S)	U	U	U	U	Q	U
28	30 mil CPE(U)	U	S	U	U	U	U
29	30 mil CPE(U)	U	S	U	U	U	U
30	30 mil HDPE(U)	S	S	S	S	S	S
31	80 mil HDPE(D)	S	S	S	S	S	S

Table 3. Performance of flexible membrane liner seams exposed to various chemicals (continued)

Sample No.	Material	Phenol	HCl	NaOH	MEK	MCL	Furfural
32	80 mil HDPE(U)	S	S	S	S	S	S
33	80 mil HDPE(U)	S	S	S	S	S	S
34	30 mil LLDPE(U)	Q	Q	Q	Q	Q	U
35	30 mil PVC(U)	U	S	U	U	U	U
36	30 mil PVC(U)	U	S	U	U	U	U
37	30 mil PVC(U)	U	S	U	U	U	U

S denotes satisfactory
U denotes unsatisfactory
Q denotes questionable
(S) denotes supported
(U) denotes unsupported

Table 4. Performance of flexible membrane liner seams exposed to water, brine, freeze/thaw cycling, wet/dry cycling and heat aging

Sample No.	Material	Water	23°Brine	50°Brine	F/T cycling	W/D cycling	Heat aging
1	36 mil CPE(S)	U	U	U	U	U	U
2	36 mil CPE(S)	S	S	S	S	S	S
3	30 mil CSPE(S)	S	S	S	S	S	S
4	36 mil CSPE(S)	U	U	U	U	U	U
5	36 mil CSPE(S)	S	S	Q	S	S	Q
6	36 mil CSPE(S)	U	U	S	U	U	U
7	36 mil CSPE(S)	S	S	Q	S	Q	Q
8	36 mil CSPE(S)	S	S	S	S	S	U
9	38 mil EIA(S)	S	S	S	Q	S	S
10	30 mil EPDM(S)	S	S	S	S	S	S
11	30 mil CPE(U)	S	S	S	S	S	S
12	30 mil CPE(U)	U	S	S	S	S	S
13	30 mil LLDPE(U)	S	S	S	S	S	S
14	30 mil PVC (U)	S	S	S	S	S	U
15	30 mil PVC(U)	S	S	S	S	S	U
16	30 mil PVC/CPE(U)	U	U	U	U	U	U

Table 4. Performance of flexible membrane liner seams exposed to water, brine, freeze/thaw cycling, wet/dry cycling and heat aging (continued)

Sample No.	Material	Water	23°Brine	50°Brine	F/T cycling	W/D cycling	Heat aging
17	36 mil CPE(S)	U	U	U	U	U	S
18	36 MIL CPE(S)	S	S	U	S	S	S
19	30 mil CSPE(S)	S	S	Q	S	S	Q
20	36 mil CSPE(S)	U	U	U	U	U	U
21	36 mil CSPE(S)	S	S	S	S	S	Q
22	36 mil CSPE(S)	S	S	S	S	S	S
23	36 mil CSPE(S)	S	S	S	U	S	Q
24	36 mil CSPE(S)	S	S	S	U	S	Q
25	36 mil CSPE(S)	S	S	Q	U	S	Q
26	38 mil EIA(S)	S	S	S	S	S	S
27	30 mil EPDM(S)	U	U	S	U	S	S
28	30 mil CPE(U)	U	S	S	S	U	S
29	30 mil CPE(U)	U	S	S	U	S	S
30	30 mil HDPE(U)	S	S	S	S	S	S
31	80 mil HDPE(U)	S	S	S	S	S	S

Table 4. Performance of flexible membrane liner seams exposed to water, brine, freeze/thaw cycling, wet/dry cycling and heat aging (continued)

Sample No.	Material	Water	23°Brine	50°Brine	F/T cycling	W/D cycling	Heat aging
32	80 mil HDPE(U)	S	S	S	Q	S	S
33	80 mil HDPE(U)	S	S	S	S	S	S
34	30 mil LLDPE(U)	Q	Q	Q	Q	Q	Q
35	30 mil PVC(U)	S	S	S	S	S	U
36	30 mil PVC(U)	S	S	S	S	S	U
37	30 mil PVC(U)	S	S	S	S	S	U

S denotes satisfactory
U denotes unsatisfactory
Q denotes questionable
(S) denotes supported
(U) denotes unsupported

SECTION 3

GUIDELINES FOR FACTORY AND FIELD SEAMING OF FLEXIBLE MEMBRANE LINERS

Factory Seaming

As discussed under the section on seaming methods, various techniques are available for factory seaming of FML's. Roll goods are furnished to the fabricator ranging from 60 in (1.52 m) to 76 in (1.93 m) in width, depending on the particular material. Only roll goods that have been previously tested and approved should be used. Close cooperation should be maintained between the manufacturer and fabricator to ensure proper seaming methods are being used.

NSF Standard No. 54 contains factory seam requirements for various FML's. The bonded seam strength requirement in shear is 80 percent of the minimum breaking strength of the parent material. For example, the minimum breaking strength of unsupported 30 mil PVC is 69 lbf/in width. Thus, the minimum shear strength requirement of the factory seam for this FML is 56.2 lbf/in width. The bonded seam requirement in peel varies depending whether the FML is supported or unsupported.

Based on the results of this and other USBR studies, the NSF factory seam requirements for shear are satisfactory. However, the peel requirements (peel adhesion) for unsupported materials such as CPE and PVC is FTB (film tearing bond) or 10 lbf/in width. Results of this study indicated that industry is capable of producing factory seams with higher peel strengths. Consequently it is recommended that the peel adhesion values for CPE and PVC be increased to 14 lbf/in width. Also the seam peel requirement for the supported CPE and CSPE materials is ply separation in the plane of the seam or 10 lbf/in width. In this study, however, ply separation only occurred to the CSPE materials that were reinforced with a 10 by 10 scrim. Thus, the requirement of ply separation for materials manufactured with a move open scrim (6 by 6, 8 by 8, etc.) may not be applicable. In addition, the peel adhesion requirement of 10 lbf/in width appears to be low, and it is recommended that this value be increased to 15 lbf/in width.

ASTM recently adopted D 4545-86, "Standard Practice for Determining the Integrity of Factory Seams Used in Joining Manufactured Flexible Sheet Geomembranes". This practice summarizes destructive and nondestructive quality control test methods for determining the integrity of factory seams by the same procedures as were used in this study (refer to Section 6). The procedure for the shear test is different than that contained in NSF Standard No. 54. For example, in NSF Standard No. 54 the seam shear test for supported materials is conducted in accordance with a modified grab method (ASTM D751), and a rate of grip separation of 300 mm/min (12 in/min). The type of test specimen used is shown in Figure 1. In this study, the test specimens were 50 mm (2 in) wide and fully supported within the grips as shown in Figure 2. The rate of grip separation was 50 mm/min (2 in/min). For the unsupported materials, the test specimens were 25 mm (1 in) wide, and the rate of grip separation was 50 mm/min (2 in/min) as compared to 500 mm/min (20 in/min) specified in NSF Standard No. 54.

Because of the differences in the procedures for evaluating the shear and peel strengths of factory seams, the quality control program should be specific as to what test procedures should be used. Eventually one test procedure will have to be adopted in order to bring uniformity to the quality control programs associated with the construction of waste disposal facilities.

Samples of the factory seams should be taken from each fabricated panel for shear and dead load testing in accordance with NSF Standard No. 54. Since production run factory seams do not contain a sufficient flap needed to conduct the peel test, representative seams will have to be fabricated periodically with the necessary unbonded overlap to conduct this test.

ASTM Standard Practice D-4545-86 lists several NDT methods for checking the integrity of factory seams. However, some developmental work will have to be done so that these appropriate methods can be used to check the factory seams in a continuous, efficient manner. This will require close cooperation with the various fabricators.

Field Seaming

Installation of the FML should be accomplished by a qualified installation contractor. The job specification should include provisions allowing the user to approve the qualifications of the installer and procedures governing the approval. The stringency of the qualifications will vary with the critical nature of the installation. Also, a representative of the FML manufacturer or fabricator should be available to provide technical assistance as required during the field seaming process.

For field seaming, the FML panels should be positioned so that the specified minimum seam overlap will be maintained along the entire edge. Jobsite factors that may influence field seaming include:

1. The ambient temperature at which the seams are produced.
2. The relative humidity.
3. The amount of wind.

4. The effect that clouds have on the liner temperature.
5. The moisture content of the subsurface beneath the liner.
6. The supporting surface on which the seam is bonded.
7. The skill of the seaming crew.
8. The quality and consistency of the bonding adhesive, if used.
9. The cleanliness of the seam interface, (i.e., the amount of airborne dust and debris present).

After the correct overlap is achieved, the field seam should be made in accordance with the FML manufacturer's directions and with materials and adhesives supplied by the manufacturer. Since solvents and flammable materials are involved with some materials, [e.g., PVC, CPE, CSPE and EPDM (ethylene propylene diene rubber)], proper safety procedures should be followed. Special attention should be given to the use and disposal of the cleaning solvents. Indiscriminate use can damage the linings.

Quality control of the field seaming process should be conducted in accordance with ASTM D4437-84, "Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes."

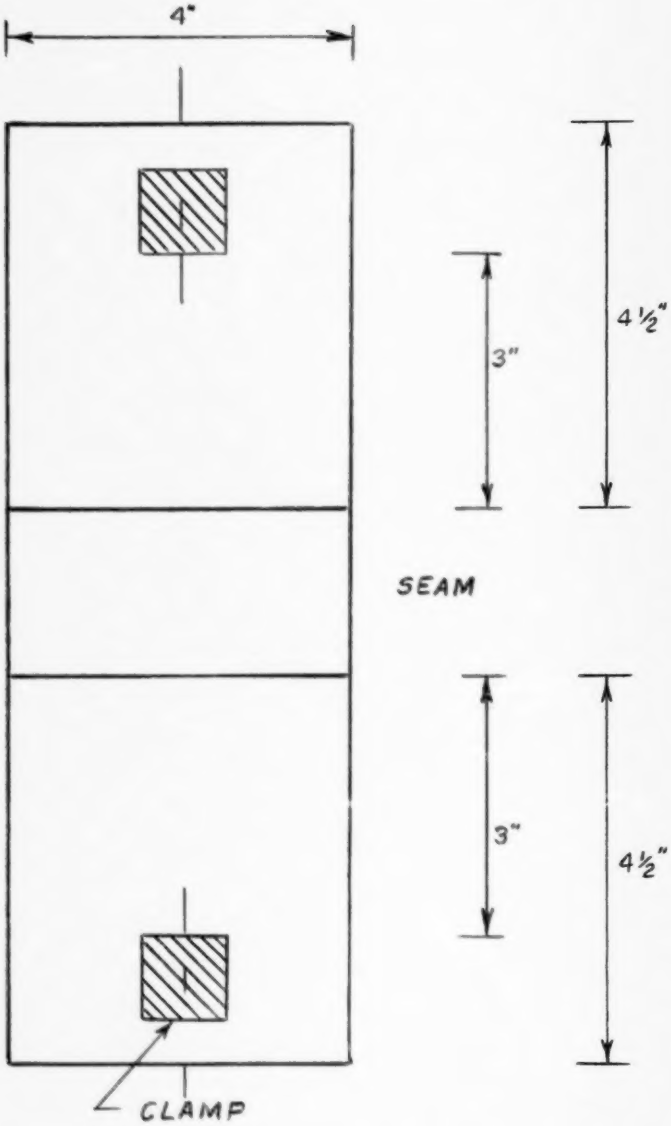
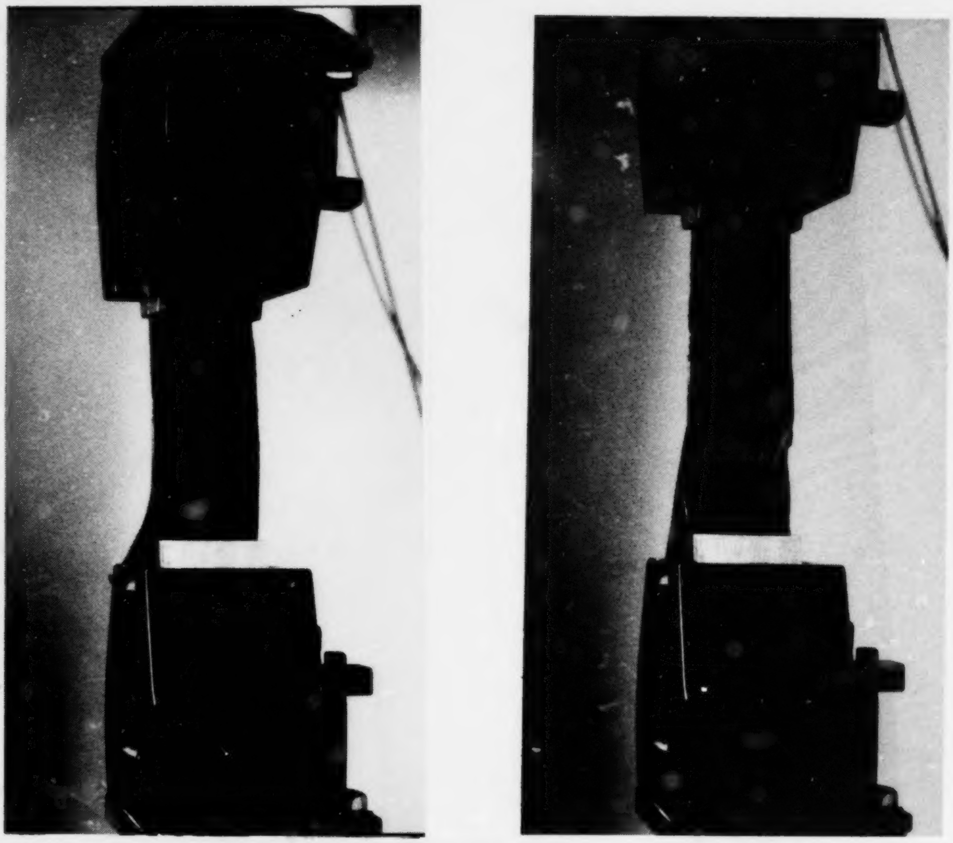


Figure 1. View of test specimen used to determine shear strength of supported flexible membrane liner seams (Modified ASTM D 751 Grab Method).



a. Initial stage

b. Final stage

Figure 2. View of dynamic shear test.

SECTION 4

SUMMARY OF LITERATURE SEARCH

USBR Literature Survey

Since 1980, the USBR has been conducting a continuous literature survey on FML's [5] (WPRS 1980). The survey is being performed at the USBR's Library at the E&R (Engineering and Research) Center in Denver, Colorado. Quarterly updates have been furnished. References pertaining to the design and construction of containment facilities include [6] (Kays, 1977), [7] (Morrison et al., 1981), [8] (Giroud and Goldstein, 1982), and [9] (EPA, 1983). Selection of FML's is covered in [10] (Fisher, 1976), [11] (Woodley, 1978), and [12] (Hatheway, 1983). Comments concerning installation procedures are presented in [13] (Small, 1980) and [14] (Schultz, 1984). Studies related to the performance and durability of FML's are given in [15] (Strong, 1980), [16] (Gunkel. 1981) [17] (Morrison and Starbuck, 1984), [18] (Haxo et al., 1984) and [19] (Nelson et al., 1985).

Interagency Technology Transfer Meeting

As part of this research project, an interagency meeting on FML research was held at the E&R Center on April 12, 1983. The following agencies and agency contractors participated in the meeting:

USBR
EPA
USNRC (U.S. Nuclear Regulatory Commission)
USATHAMA (U.S. Army Toxic and Hazardous Materials Agency)
CERL (U.S. Army Construction Engineering Research Laboratory)
EPRI (Electric Power Research Institute)
LANL (Los Alamos National Laboratory)
Battelle Pacific Northwest Laboratory

The purpose of the meeting was to discuss current research studies being conducted by the various agencies on FML's. A matrix of FML research versus agency involvement is shown in table 5.

Studies of interest to this EPA project included those by Battelle's Pacific Northwest Laboratory on NDT methods and the performance of FML's for uranium tailing ponds [3] (Mitchell and Spanner, 1984) [20] (Mitchell, 1984). Other studies of interest included the evaluation of liner specimens from three existing landfill sites [21] (EMCON, 1982), and effect of flue gas cleaning sludges on selected liner materials [22] (Styron et al., 1981).

Geotechnical Conferences

In June of 1984, the USBR along with several other organizations including EPA cosponsored the International Conference on Geomembranes in Denver, Colorado. Ninety-five technical papers from 13 countries were presented on the state-of-the-art of FML's.

Several papers were presented at this conference on the fabrication and testing of FML seams, [23] (Frobel, 1984), [24] (Seaman 1984), [25] (Spanner, 1984) and, [26] (Price, 1984).

In 1985, several papers were presented at the Geotechnical Fabrics '85 Conference in Cincinnati, Ohio, and at the Second Canadian Symposium in Edmonton, Alberta, Canada, on the testing and evaluation of HDPE field seams [27] (Peggs, 1985), [28] (Peggs and Little, 1985), and [29] (Peggs et al., 1985).

Table 5. MATRIX OF FML RESEARCH VS. AGENCY INVOLVEMENT, April 1983

FML research topic	Agency						
	USBR	USEPA	USNRC	USATHAMA	EPRI	CERL	LANL
Dead load Testing - Seams	X						
Evaluation After Aging - Seams	X	X	X				
Nondestructive Seam Testing	X	X	X				
Field Seaming Procedures/ Evaluation	X						
GCMS Analysis of FML	X						
FML Failure Mechanisms		X					
Polymer Chemistry vs. Aging		X					
Chemical Compatibility/ Resistance	X	X	X	X			
Accelerated Aging of FML	X	X	X	X			
FML/Soil Cover Interaction	X	X					
Impoundment Construction Techniques		X	X				
Prevention of H_2 Contamination		X	X				
Gas Desulpherization of Waste/ Use of FML		X					
Leak Detection Techniques		X	X				X
Hazardous Waste/FML Compatibility		X			X		
Evaluation of Old Installations	X	X	X			X	
FML Repair Procedures		X	X			X	
FML Covers - Landfills		X				X	
Subgrade Anomaly Conformance	X		X				
Restoration of Old Installations				X			
Utilities Waste Containment					X		
Soil Cover - Seepage Prevention							X
Soil Cover - Infiltration Characteristics							X
Prediction of Subsidence - Soil/FML Cover		X					
Low-Level Radioactive Waste Containment			X		X		X

SECTION 5

SEAMING METHODS

General

FML seaming methods depend on the polymer composition of the lining material. Some materials can be seamed or bonded together by several different methods, whereas others can be seamed by only one. The most common seaming methods for FML's are listed below [23, 24, and 30]:

1. Methods involving solvents or cements including solvent bonding, bodied solvent adhesive, solvent adhesive, and contact adhesive.

2. Methods involving heat only (thermal methods) such as electronic (dielectric), hot wedge, or hot air.

3. Methods involving the introduction of a hot base product such as the extrusion or fusion welding process.

4. Methods involving the vulcanization process with uncured gum tape or adhesives.

5. Methods involving tapes only including polyethylene tape or uncured gum tape.

6. Methods using only mechanical friction connections or mechanical sewing.

Bonding methods which utilize solvents and adhesives are normally used on thermoplastics or thermoplastic elastomers; whereas, contact adhesives can be used on most polymeric liners.

Thermal seaming methods are applicable only to FML's composed of base products sensitive to heat, i.e., thermoplastics, crystalline thermoplatics, and thermoplastic elastomers. Extrusion welding processes are used exclusively on the crystalline thermoplastic HDPE (high-density polyethylene) sheet materials, usually in field seaming of a system. Vulcanization is used on the elastomer-type FML's. Mechanical methods could be used on many of the thinner sheets but is predominately used on the thinner polyethylenes and some coated fabrics. All seaming methods could be used in the factory or in the field fabrication process with the exception of the thermal dielectric method and vulcanization which are used only in factory fabrication. Tapes and mechanical methods are found predominately in field installation practice.

The following are general descriptions of methods in use today. (Refer to tables 6 and 7 for an overview of seam methods used in factory and field fabrication.)

Liquid Applied Solvent or Adhesive Systems

Solvent bonding. - For solvent-bonded seams, a solvent recommended by the sheet manufacturer is used to soften the surfaces to be bonded which effects a homogeneous bond between the membranes after application or pressure. The solvent will eventually dissipate and does not remain as part of the bond. Usually, seaming must be accomplished only when sheet and adhesive temperatures are above 15.5 °C (60 °F). If only ambient temperatures create conditions where temperatures are lower than this, auxiliary means of surface area heating must be used, such as heat guns or portable radiant heaters.

Bodied solvent adhesive. - A bodied solvent adhesive is prepared by dissolving approximately 8 to 12 percent of the liner compound in a recommended solvent and applying the liquid to the surfaces to be bonded, effecting a homogeneous bond after application of pressure and evaporation of the solvent.

Solvent adhesive. - A liquid-applied solvent adhesive is used to develop bond strength between two sheets by means of an adherent left after dissipation of the solvent. This adhesive system is also referred to as a solvent cement. The adhesive becomes an additional element in the seam system effecting a surface-to-surface bond but not a homogenous bond. Sufficient rolling pressure must also be used to produce an acceptable adhesion.

Contact adhesive. - This material, as recommended by the sheet manufacturer, is applied, usually by brush or roller, to both lining surfaces to be joined. After the adhesive has attained the proper degree of tackiness, the two surfaces are immediately joined together. The use of this type of adhesive requires careful alignment of the lining material before bonding because the joined surfaces should not be realigned after assembly. After joining, the seam should be rolled with a steel or plastic roller in a direction perpendicular to the edge of the seam. The adhesive forms a bond and remains as an additional element within the seam.

Thermal Methods

Thermal seaming methods are used on thermoplastics, crystalline thermoplastics, and thermoplastic elastomers in which the base polymer is sensitive to heat and readily softens or melts. In practice, the surfaces of the two polymer sheet materials to be joined are first softened or melted and then immediately pressed together to form a "melt" bond that extends into the first few mils of thickness of the sheet (melt depth is dependent on heat source temperature, dwell time, and sheet temperature). There are basically three methods of producing a thermal bond: Hot air; hot wedge (hot knife), and electronic or dielectric bonding.

Hot air methods. - Hot air can be used on most of the thermoplastic and thermoplastic elastomer materials as shown in table 7. A machine consisting of resistance heaters, a blower, and temperature controls directs a blast of hot air or gas usually in excess of 260 °C (500 °F) between two polymer sheet materials, thus melting the surfaces. Immediately following the surface melt, pressure (usually by rollers) is applied to bond the area to form a homogenous seal between the two membranes at the seam overlap. The heat-producing machine can be either a hand-held unit for the field or a large, automated factory machine with preset controls for temperature, movement rate, and roller pressure.

Hot wedge. - The hot wedge method (also called hot knife) consists of a hot electrically heated resistance element in the shape of a blade or V-shaped wedge that is passed between the two sheets to be sealed and is in intimate contact with them, thus melting the surfaces. Immediately following the melting, roller pressure is applied effecting a homogenous bond. The hot wedge method is particularly suited for the thicker [greater than 0.76-mm (30-mils)] LLDPE (linear low-density polyethylene) and HPDE materials, but could also be adapted for use on the reinforced thermoplastics. Single hot wedge and dual hot wedge systems are presently available. The dual hot wedge weld forms a continuous air channel between the two welded seams which is used for testing the bond continuity by injecting air pressure. Welding rate (movement of the machine) as well as temperature and roller pressure are adjustable and continuously monitored. Adjustments are made according to environmental conditions such as ambient temperature and moisture. The hot wedge method can be used in both the factory fabrication of panels and in field installation.

Dielectric. - Electronic bonding commonly referred to as dielectric is used on thermoplastic and thermoplastic elastomer materials and is carried out only in a fabrication plant. A rapidly reversing electric field is used to effect rapid realignment of molecules at a high rate within the polymer structure. This rapid realignment by reversing field polarity causes internal friction with the compound, thus, generating heat very rapidly. Electronic bonding machines are large and consist of a top electrode bar approximately 25 mm (1 in) or less in width, a large bottom electrode plate, a high-frequency oscillator tube, a pressure system to clamp the sheet being seamed, and a high-voltage transformer. Because of their bulk, power requirements, and need for cleanliness, dielectric machines are used only in an enclosed factory production facility. The machines run on 220 volts and produce up to 10 kilowatts of power while operating in a 27-MHz radio frequency range. The two polymer sheets to be bonded are placed as a lap joint between the electrode bar and bottom plate and held in position by mechanical pressure from the top electrode. Electrical current is turned on for 1 to 3 seconds transmitting the high frequency through the overlap causing the sheet material to soften and melt together forming a homogenous bond. The top electrode bar is normally 0.61 to 1.23 meters (2 to 4 ft) in length. As the sheets are passed through the electrode, the ends of the bonded areas are overlapped, thus forming a continuous seam.

Extrusion Welding Methods

Extrusion welding is currently employed in the field joining of HDPE sheets ranging in thickness from 0.5 to 3.0 millimeters (20 to 120 mils). It consists of extruding a ribbon of molten polymer of the same resin as the parent sheet between two mating surfaces or at the edge of two overlapped sheets thus effecting a homogenous bond under optimum conditions. If extrudate is placed between two overlapped sheets, the technique is referred to as flat welding. This is accomplished by means of a self-propelled extrusion welder which is designed to systematically separate the overlaps, preheat the weld area, extrude a bead of molten resin, and pressure roll the weld area. All temperatures and speed of welding are controlled automatically and are very carefully preset according to ambient conditions.

If a bead of molten resin is placed at the edge of a seam, the technique is called a fillet weld or hand extrusion weld. The extrusion machine, although smaller, is also carefully preset as to temperature of preheat air and extrudate.

For either type of weld, the following operations are carried out to effect seaming of the HDPE sheets:

1. Position the sheets with manufacturers' recommended overlap.
2. Roughen weld area to be welded with a hand electric grinder.
3. Extrude molten resin between or at the edge of the overlapped sheets.
4. Provide roller pressure for flat welding.
5. Inspect and test the weld.

Depending on the manufacturer of the sheeting, the fillet-type weld area may or may not be preheated with hot air.

Vulcanizing Tapes and Adhesives

Because of the density or tightly packed molecular arrangement of vulcanized elastomers such as butyl and EPDM, these materials possess excellent impermeability by impeding the movement of moisture or moisture vapor. However, because of the cross-linked structure, the polymer will not go into solution with solvent systems to form a bonded joint. In addition, thermal methods that are used on the thermoplastic materials do not provide acceptable bonding on vulcanized elastomeric sheet materials. To provide a strong bond, an uncured tape or adhesive containing the polymer base of the liner and cross-linking agents (usually sulfur or sulfur-bearing compound) is placed between the overlaps of two cured (vulcanized) elastomer sheets. Upon application of heat and pressure at the seam area, molecular cross linking (vulcanization) of the polymer base in the tape occurs, thus achieving a bond strength between the two sheets not attainable with ordinary adhesives. Factory vulcanization of seams is usually accomplished in a large vulcanizing press or an autoclave, whereas field seams can be fabricated using the uncured tape and a portable seaming machine that provides the necessary heat and pressure with a bar.

Tapes and Mechanical Seaming

In addition to the more complicated methods of seaming polymer sheets, relatively simple and quick methods of joining are also available that may be fully acceptable for certain applications.

Tape seams are made by applying an adhesive-backed strip between or at the edge of two sheets. The tape provides tensile strength to the joint; however, the tape backing and adhesive may be different than the polymer sheet, thus, introducing two additional elements to the seam system. The resulting seam will not be considered homogeneous and, thus, its limitations as to long-term integrity must be recognized.

Mechanical methods of seaming use no adhesives or thermal joining but rather rely on the friction between two sheets using some type of pressure or clamping system or mechanical sewing. The simplest friction seam is that employing a 0.3- to 1-meter (1- to 3-ft) overlap of an FML with soil cover material. The soil cover placed over the lining provides overburden pressure to hold the overlapped sheets in place. This procedure is often used in USBR plastic canal lining work where 100 percent seepage control is not required. A more sophisticated mechanical seam method uses an inner rod and an outer "C" clamp of flexible polymer material to hold two sheets together. A mechanically sewn seam provides tensile strength but must be waterproofed with a liquid field-applied sealant material.

Table 6. Adhesive-type seaming methods for flexible membrane linings

Lining material	Solvent		Bodied solvent		Solvent adhesive		Contact adhesive		Vulcanizing tape/adhesive		Tapes
	M	F	M	F	M	F	M	F	M	F	F
Thermoplastics											
Polyvinyl chloride (PVC)	X	X			X	X	X	X			X
Nitrile - PVC (TN -PVC)	X	X			X	X	X	X			X
Ethylene interpolymer alloy (EIA)											
Crystalline thermoplastics											
Low-density polyethylene (LDPE)							X	X			X
High-density polyethylene (HDPE)							X	X			X
Elastomers											
Butyl rubber (IIR)							X	X	X	X	X
Ethylene propylene diene monomer (EPDM)							X	X			X
Neoprene (polychloroprene)							X	X			X
Epichlorohydrin rubber (CO)							X	X			
Thermoplastic elastomers											
Chlorinated polyethylene (CPE)	X	X	X	X	X	X	X	X			X
Chlorosulfonated polyethylene (CSPE)	X	X	X	X	X	X	X	X			X
Thermoplastic EPDM (T-EPDM)							X	X			

Note: M = Manufactured or factory seams.
F = Field fabrication.

Table 7. Thermal and mechanical seaming methods for flexible membrane linings

Lining material	Thermal methods					Extrusion (fusion) welding	Mechanical
	Hot air		Hot wedge		Dielectric		
	M	F	M	F	M	F	F
Thermoplastics							
Polyvinyl chloride (PVC)	X	X			X		X
Nitrile - PVC (TN -PVC)	X	X			X		X
Ethylene interpolymer alloy (EIA)	X	X					
Crystalline thermoplastics							
Low-density polyethylene (LDPE)	X	X	X	X			X
High-density polyethylene (HDPE)		X	X	X		X	X
Elastomers							
Butyl rubber (IIR)							
Ethylene propylene diene monomer (EPDM)							
Neoprene (polychloroprene)							
Epichlorohydrin rubber (CO)							
Thermoplastic elastomers							
Chlorinated polyethylene (CPE)	X	X			X		
Chlorosulfonated polyethylene (CSPE)	X	X			X		
Thermoplastic EPDM (T-EPDM)	X	X					

Note: M = Manufactured or factory seams.
F = Field fabrication.

SECTION 6

LABORATORY TEST PROGRAM

Liner Materials Evaluated

The polymeric materials evaluated for this study were obtained in 1983 from 13 industry representatives who manufacture or fabricate FML's commonly used in pollution and seepage control. Manufacturers and fabricators were contacted and asked to participate in the study in an attempt to obtain a broad selection of recommended membrane types (including supported and unsupported samples), scrims, and seaming techniques.

Polymer sheet materials submitted by industry for this study included the following:

HDPE 30-mil unsupported
HDPE 80-mil unsupported
LLDPE 30-mil unsupported
EPDM 30-mil supported
PVC 30-mil unsupported
CPE 30-mil unsupported
CPE 36-mil supported
CSPE 36-mil supported
EIA 38-mil supported

Two or more sources submitted additional samples and/or seaming methods of PVC, HDPE, CPE, and CSPE as well as one composite seam of PVC/CPE. Different manufacturing methods including varying scrim types, thickness, and seaming methods were represented in the submittals. The factory seams evaluated in this study are listed in table 1. Photographs of some of the seams evaluated are shown in Figures 3 through 8.

Field Seams

The field seams were fabricated at the USBR Engineering and Research Center from the polymer roll goods that were furnished along with factory seams from industry. The field fabrication was accomplished by a third party commercial installer under USBR supervision. The installer hired two laborers from a local manpower office and trained them in the various techniques associated with the field seaming of FML's.

The field seams were made in accordance with the manufacturer's and or fabricator's instruction and products as required. Technical assistance and special seaming equipment were furnished by the manufacturers to field seam the 30 and 80 mil HDPE liner (extrusion fillet weld), and the 30 mil LLDPE liner (thermal-hot wedge). Several field seams which could not be fabricated at the USBR facility were witnessed and collected at job sites under USBR direction. These included the 80 mil HDPE extrusion lap weld, the 80 mil HDPE thermal-hot dual wedge, and the 38 mil EIA thermal-hot air seam.

The seaming methods and types of field seams evaluated in the study are summarized in table 2. Some of the field seaming work performed at the Bureau facility are shown in figures 9 and 10.

Chemical Immersion

Six chemical solutions were chosen to represent a wide range of chemical groups. These solutions were:

10 percent phenol (organic acid)
10 percent hydrochloric acid (inorganic acid)
10 percent sodium hydroxide (inorganic base)
10 percent methyl ethyl ketone (ketone)
5 percent furfural (aldehyde)
100 percent methylene chloride (halogenated hydrocarbon)

Methylene chloride is not soluble in water; therefore, pure solvent was used to avoid the problem of phase separation. Pure chemicals or aqueous chemical solutions were selected for testing rather than simulated or actual wastes from waste sites to simplify verification of testing procedures. The use of representative groups of chemicals also allows for reasonable interpretation of the data.

To provide proper storage and handling facilities for the various chemicals, a local analytical laboratory was contracted to provide the chemical immersion. Their contract included the following work:

1. Procurement of chemicals.
2. Provide temperature-controlled and vented storage for 18 tanks for 1 year.
3. Monitor the tanks for concentration and maintain a log.
4. Remove the samples with a USBR representative present after 3, 6 and 12 months of immersion.
5. Rinse the surfaces of the samples with distilled water when removed from immersion.
6. Immediately store the samples in sealed containers for transfer to the USBR for dead load testing.
7. Conduct shear and peel tests on the FML seams.
8. Dispose of all spent chemical solutions in accordance with EPA guidelines.

Exposure Methods

Liquid. - All FML factory and field seams were cut into large samples for environmental exposure. The unsupported seams were cut into 300-millimeters (12-in) wide samples in order to later yield twelve 25-millimeters (1-in) wide specimens for mechanical testing and the supported samples were cut into 450-millimeters (18-in) wide samples to provide four 50-millimeters (2-in) wide and eight 25-millimeters (1-in) wide specimens. The edges of these samples were not sealed. Therefore, to minimize the effect of wicking, 25 millimeters (1 in) of each edge of the scrim-reinforced samples were cut off and discarded. All samples were attached with polypropylene ties to fiberglass rods for exposure testing as shown on figure 11.

Chemical, brine, and water immersion of seam samples was accomplished in covered 170-liter (45-gal) capacity polypropylene and polyethylene tanks. These tanks were filled separately with each of the liquids and the seam samples were then suspended into the liquids.

Three tanks of room-temperature tapwater and six tanks of saturated sodium chloride brine solution [three tanks at room temperature and three at 50 °C (122 °F)] were also set up for immersing samples at the USBR Laboratory. The samples, except for the room temperature brine (B23), were removed and tested after 3, 6 and 12 months of immersion. Due to an error in scheduling, the room temperature brine samples were only tested after 3 and 12 months of immersion.

The remaining samples were either placed in running tapwater for 6-month saturation before beginning freeze-thaw or wet-dry cycling tests or set aside for heat aging tests. Double-sided exposure of all samples was used to accommodate the large number of samples in minimum space. An advantage of double-sided exposure over single-sided exposure was the reduced time needed to see the effects of the liquids on the samples. In parallel with the tank immersions, smaller coupons of the parent materials were immersed in small, clear glass jars for periodic weight and thickness measurements. The smaller coupons allowed for easier inspection of the polymeric sheet materials for obvious excessive degradation, swelling, or change in color or surface texture. If any accelerated response was observed in the coupons, the seam samples were removed from the larger tanks before they were destroyed completely. The ratio of the volume of liquid to the surface area for each coupon was 6.2 $\mathrm{mL/cm^2}$ (40 $\mathrm{mL/in^2}$).

Heat aging. - Many liner systems are installed in the warmer climates of the world where higher temperatures often may be destructive to the liner material. Seam samples were subjected for periods of 4, 8, and 13 weeks of oven-aging at 70 °C (158 °F) in an effort to provide an accelerated test of long-term heat effects on the seam systems.

Environmental cycling. - To determine the effects of cyclic stress on the various seam systems, short-term freeze/thaw and wet/dry cycling were carried out on seam samples that had been in tapwater for 6 months.

Presently, little information is available concerning the longterm effects on physical properties of subfreezing temperatures, especially for those liners that tend to absorb water. Seam samples were subjected to alternating cycles of freezing for 16 hours at 20 °F and thawing for 8 hours in room-temperature water. They were tested after 10, 20, and 50 cycles. Wet/dry cycling represents the fluctuating liquid/liner/air interface where severe weathering can take place. Seam samples were tested after 10, 20, and 50 wet/dry cycles. These cycles alternate 16 hours of water immersion at room temperature followed by 8 hours of drying at 37.7 °C (100 °F).

EMMAQUA. - In addition to the above exposure conditions, the DSET (Desert Sunshine Exposure Test) Laboratories in Phoenix, Arizona, were contracted to perform accelerated outdoor sunlight exposure testing on 32 representative seam samples. The exposures were accomplished on the EMMAQUA accelerated weathering test machines located at the test facility as shown on figure 12. The EMMAQUA machines are capable of tracking the sun and focusing the sun's rays on the 5-inch-wide seam specimens for optimum UV (ultraviolet) exposure. These machines utilize 10 polished mirrors to direct the maximum intensity onto the target sample area. The accelerated rate of degradation of the EMMAQUA exposure is approximately eight times that of conventional outdoor exposure. For 8 minutes of every sunlight hour, deionized water is sprayed on the samples, providing wetting and drying. A special air distribution system forces air over and under the samples so that their surface air temperatures are approximately equal to those of a liner at a conventional 45° south exposure. The samples were visually inspected and photographed after 6 months of exposure. After 1 year of exposure, the samples were again inspected and photographed, and then returned to the USBR where they were tested for peel strength retention and observed for any obvious deterioration. Originally, samples were to be tested after 3, 6 and 12 months of exposure, but this was limited to 12 months only due to budget limitations.

Test Methods

Weight and thickness. - Coupon samples of the parent materials listed in table 8, were measured for weight and thickness before immersion. The 21 coupon samples, each with dimensions of 50 millimeters by 125 millimeters (2 in by 5 in), were measured after 1, 2, 3, 4, 8, 12, 36, and 52 weeks of immersion.

Initial mechanical properties. - Initial mechanical properties testing was done on the unexposed seam samples for all lining materials. The data collected represent the virgin materials and seams in an unsaturated state as received from the factory or the field fabrication.

Periodic mechanical properties. - After completion of the liquid immersions and the required environmental conditioning intervals, the mechanical tests listed below were performed to determine changes in physical properties. As discussed in Section 3, the dynamic shear and peel tests were conducted in accordance with the test procedures described in ASTM D 4545-86, "Standard Practice for Determining the Integrity of Factory Seams Used in Joining Manufactured Flexible Sheet Geomembranes".

1. Dynamic tensile shear testing. - Fifty-millimeters (2-in) wide supported or 25-millimeters (1-in) wide unsupported seam specimens were tested in tensile shear using dynamic loading at a low-strain rate of 0.8 mm/s (2 in/min) with an initial grip separation of 25 millimeters (1 in) plus the seam width of the liner. The supported samples were wider for tensile testing in an effort to eliminate edge effects due to the scrim reinforcement. Results indicate strength in lbf/in of seam width and mode of failure. A view of the shear test is shown in Figure 2.

2. Dynamic peel testing. - Twenty-five-millimeters (1-in) wide specimens were subjected to 180° peel at a strain rate of 0.8 mm/s (2 in/min) with an initial grip separation of 25 millimeters (1 in). Results indicate strength in lbf/in width of seam and mode of failure. A view of the peel test is shown on figure 13.

3. Static dead load peel testing at elevated temperature. - Twenty-five-millimeter-wide (1-in) specimens were subjected to a 180° peel dead load of 1022 g at a temperature of 50 °C (122 °F) for a minimum of 4 hours or until failure occurs under 4 hours. Due to the wide variety of sheet materials, seam types, and failure modes, this single weight was chosen to test all seam interfaces. This weight represents a very low percentage of material breaking strength per inch of seam width, but is intended to test the seam interface integrity at elevated temperature. Results are expressed by pass/fail and mode of failure. Equipment used in this test is shown on figure 14.

Evaluation procedures. - Tests results of exposed seam samples were compared to the test results of original unexposed seam samples for all tests. The mode of failure was evaluated as well as the numerical results of shear, peel, and dead load in lbf/in of seam width. The description of the failure modes is given in table 9, and shown visually on figures 15 through 21.

Nondestructive seam testing

Several methods are available for qualitatively testing seams without taking samples from a completed lining system. These nondestructive test methods can be used to measure the continuity of a seam but cannot be used to quantitatively measure the relative strength of the joint nor the projected future performance. These methods should be used in conjunction with destructive methods in a quality assurance program. Table 10 summarizes the available NDT methods which are briefly described below.

Electronic methods. - Two electronic methods have been proven to work on detecting unbonded areas in FML seams. These are the UPE (ultrasonic pulse echo) and the UIP (ultrasonic impedance plane) techniques.

The UPE technique is presently used in the field for testing continuity of HDPE flatwelds. However, this method works equally well on other unsupported liners. Basically, the technique is a thickness measurement using a high frequency pulse of energy transmitted into a seam. The high frequency pulse (5-15 MHz) is transmitted via a surface transducer through both sheet thicknesses and returned to a receiving oscillator after reflecting off the lower sheet bottom surface. If the seam is homogeneous, the pulse echo will indicate a characteristics curve on a time-based CRT (cathode ray tube) monitor. If there is a discontinuity which would include an unbonded area as well as foreign materials present, a change in signal will indicate the discontinuity on the monitor as shown in Figure 22. To assure good bonding across the seam width, the entire seam surface area must be scanned with the UPE transducer. The operator visually inspects and marks all unbonded areas for repair. Views of the UPE technique conducted at the USBR facility are shown in figure 23.

The UIP technique works on the principle of characteristic acoustic impedance. A well-bonded joint possesses a certain acoustic impedance after calibration and any other area that is not as well bonded possesses a different acoustic impedance. A continuous wave resonant frequency of 160-185 kHz is transmitted by means of a surface transducer, as shown in Figure 24, and a characteristic dot pattern is established on a CRT monitor. Location of the dot pattern on the screen as shown in Figure 25 indicates a good bond, an unbond, or an uncoupled transducer. This method, although not yet widely used, can be applied to supported as well as unsupported FML's as the scrim reinforcement does not seem to affect the low frequency transmission.

Both of the above methods require a surface transducer wide enough to be able to scan the full width of a given seam along the entire bonded length. Improvements in method of application for both systems are needed to increase the speed of testing as well as the accuracy. Present speed of testing is only 1 to 2 m/min (3 to 6 ft/min).

Air lance. - This method requires that a jet of air 342.5 kPa (50 psig) regulated and directed through a 4.8 millimeters (3/16-in) diameter nozzle be applied to the upper edge of an overlap seam in an effort to detect an unbonded area. When correctly used, the impinging air stream, held not more than 50mm (2 in) from the seam edges will inflate an unbonded area which is then marked by the inspector for subsequent repair. The air lance method requires a portable compressor in the field and can effectively test seams at the rate of approximately 4 m/min (13 ft/min). This method, shown in Figure 26, was used by the Bureau to check factory and field seams during the installation after Mt. Elbert FML installation [8].

Vacuum chamber. - The equipment needed for a vacuum seam test consists of a vacuum box capable of being sealed to a seam area with a glass viewport and a portable electric vacuum pump. The rubber seal of the chamber bottom is first soaped to provide a vacuum seal and then the seam edge is covered with a soapy solution. When a vacuum is applied to the chamber (usually less than 17.2 kPa (2.5 psig)), an unbonded area indicated by the presence of bubbles. The unbonded area is marked for subsequent repair. Speed of testing is usually 1.5 to 3 meters (5 to 15 ft) per minute with one operator. Figures 27 and 28 show some of the vacuum seaming performed at the USBR facility.

Pressurized dual seam. - This method is utilized on a double wedge thermally welded seam where an air chamber exists between two bonded lengths of seam. After the dual wedge seam has been fabricated for a given length, both ends are sealed. A needle with attached pressure gauge and air valve is inserted into the air space between the thermally welded areas, and pressure [usually 207 kPa (30 psig)], is applied to the air channel. The gauge is monitored for drop in air pressure over time as an indicator of a seam unbond and leak. Although this method tests long lengths of a seam at one time, the entire length must be rechecked with a vacuum box or the length must be cap stripped if a leak is detected. The pressurized dual seam is presently in use on thermally welded HDPE but could be used on other polymer sheet materials capable of being seamed with a dual wedge welder.

Electrical sparking. - Although rarely used, electrical sparking methods can effectively detect voids, pinholes, or unbonds primarily in the crystalline thermoplastic welds. A high-voltage (15-30 kV) electrical current is applied to a seam area, and any leakage to ground can be detected by sparking. A ground wire can be designed into the FML system and attached to the back of a seam for subsequent use of the spark test apparatus. This method was not evaluated in this study since it does not have widespread application.

Mechanical point stress. - To detect unbonded areas, an inspector can slide a dull tool (such as a blunt screwdriver) along the top edge of a bonded seam. A weak or unbonded area will be easily lifted and then marked for repair. Care must be exercised when using this method so as not to puncture the FML or use excessive force against the seam edge. This method is also referred to as the "pick test."

USBR Tests. - The electronic methods were performed at the USBR with equipment and personnel supplied by Battelle Pacific Northwest

Laboratories, Richland, Washington.[25] The remaining techniques were performed and evaluated by USBR personnel.

Quality Assurance Program

General. - The quality assurance program followed standard USBR practice for a research study of this type. This practice consists of three major procedures, each having several elements: quality analysis, quality control, and quality assessments.

Quality analyses. - This procedure involves the examination of program elements, operation and goals to determine what special problems or difficulties may be encountered. In this study, the majority of the data was to be obtained by relatively simple equipment and routine techniques. Equipment for obtaining sample weight, seam strength properties and creep resistance is easily calibrated and convenient to check at frequent intervals. Furthermore, the materials, their properties and behavior were, in general, well known to the participating staff. Since the goals of the study were primarily concerned with material change rather than absolute value, consistency in all aspects of the work was of paramount importance. Samples were taken from manufactured products, and thus did not require complex preparation. Data security needed only the usual caution since no current litigation was dependent on the outcome of the results. For these reasons, heroic measures were considered not necessary for most control aspects of the study.

Special attention was necessary for the work performed by the contract laboratory. This was accomplished by limiting the work to simpler more routine testing, selection of a company with a past record of reliability, frequent observation of their operations, and random duplication of testing in the USBR laboratory.

Quality control. - This involves developing methods to minimize introduction of error into data acquisition and manipulation. The elements given primary attention were personnel qualifications, equipment reliability, appropriate procedures and close supervision. Only seasoned technicians were chosen to work on this study. Their laboratory experience with the USBR ranged from a minimum of 7 years to over 40 years. Each individual was assigned to tests most appropriate to their special skills and this was emphasized to them to obtain the highest motivation for accurate work. All individuals receive regular formal training, the senior technicians are certified by the Institute for Certification of Engineering Technicians, and special group discussions were held to promote each individual's understanding of the entire project as well as specific aspects of their own work.

Equipment reliability was maintained both by long established contracts with qualified firms for annual or semiannual calibration, and by regular calibration checks performed in-house. Where appropriate to minimize variation, testing was performed in an environment controlled to 50 percent ± 5 percent relative humidity and 73.4 ° ± 1.8 °F (23 ° ± 1 °C). Standard ASTM test procedures were used to the greatest extent possible. Exceptions were fully documented and discussed in technician training briefing, to promote uniformity. Close supervision was maintained by regular involvement of senior technician staff and initial involvement of professional staff during any test startup to ensure good laboratory practice. Both principal investigator and management frequently observed test operations, approved standard operating procedures, and participated in training briefings.

Quality assessment. - This involves the implementation of procedures designed to evaluate effectiveness of the established controls. Internal methods, used to evaluate bias and lack of precision included interchange of equipment operators and, where possible, of test equipment. The repetitive nature of the process of testing at various time intervals as well as use of replicate specimens provided the type of data that would help pinpoint accuracy problems. External processes are continously utilized to provide independent measure of the effectiveness and quality of the control process. USBR external checks are implemented by assembling duplicate sets of test materials to be tested by our laboratory and other Government or independent testing laboratories. Additional examination occurs through the nature of our CQA program. Every year we test materials for several dozen manufacturers of construction products. Our data are regularly compared with the manufacturer's data. The inspection of procedures becomes quite intense when large sums of money are involved in rejection of proposed materials. Overall, the review of both the internal and external processes by experienced professionals who are familiar with the test equipment, test methods, and the materials has been effective in quickly identifying problems.

Table 8. Samples for weight and thickness determinations

Sample I. D.	Manufacturer	Lining material	Scrim reinforcement
A	A	36-mil CPE	6 x 6 leno polyester
B	H	36-mil CPE	10 x 10 polyester
C	B	30-mil CSPE	8 x 8 polyester
D	B	36-mil CSPE	6 x 6 polyester
E	B	36-mil CSPE	10 x 10 polyester
F	A	36-mil CSPE	6 x 6 leno polyester
G	G	36-mil CSPE	10 x 10 polyester
H	G	36-mil CSPE	10 x 10 polyester
I	I	36-mil CSPE	10 x 10 polyester
J	J	38-mil EIA	polyester
K	C	40-mil EPDM	10 x 10 nylon
L	E	30-mil CPE	-
M	E	30-mil CPE	-
N	D	30-mil HDPE	-
O	D	80-mil HDPE	-
P	F	80-mil HDPE	-
Q	K	80-mil HDPE	-
R	B	30-mil LLDPE	-
S	E	30-mil PVC (gray)	-
T	E	30-mil PVC (black)	-
U	I	30-mil PVC (gray)	-

Table 9. Description of failure modes

Failure mode	Description of failure mechanism
1	Parent material failure at clamp edge.
2	Parent material failure at seam edge.
3	Within the adhesive bonding system.
4	Planar failure between adhesive and liner surface or between two thermal-bonded surfaces
5	Scrim delamination and pullout.
6	Failure in parent material (other than 1, 2, or 5).
7	Scrim break within seam and subsequent pullout.
8	Initial peak with subsequent ply separation (peel tests on supported samples only). Results are shown as initial peak load/ply adhesion.
9	No failure - maximum extension of machine reached, maximum load cell range reached, or yield of parent material reached with subsequent elongation.

Table 10. Recommended NDT methods based on this research

FML	Thickness (mils)	Ultrasonic pulse echo (5-15 MHz)	Continuous wave resonant frequency (167 kHz)	Air lance	Vacuum chamber	Double seam pressurization	Mechanical point stress
Supported CSPE and CPE	30		*	*	*		*
	36		*	*	*		*
	45		*	*	*		*
	60		*		*		*
Unsupported CPE	20	*	*	*			
	30	*	*	*	*		*
Unsupported PVC	20	*	*	*			
	30	*	*	*	*	*	
	40	*	*	*	*		*
Unsupported HDPE HDPE-A LLDPE	20	*	*		*	*	
	30	*	*		*	*	*
	40	*	*		*	*	*
	60	*	*		*	*	*
	80	*	*		*	*	*
	100	*	*			*	*
Supported EPDM and BUTYL	30			*	*		*
	45			*	*		*
	60				*		*
Supported EIA	38				*		*

1 mil = 0.0254 mm.

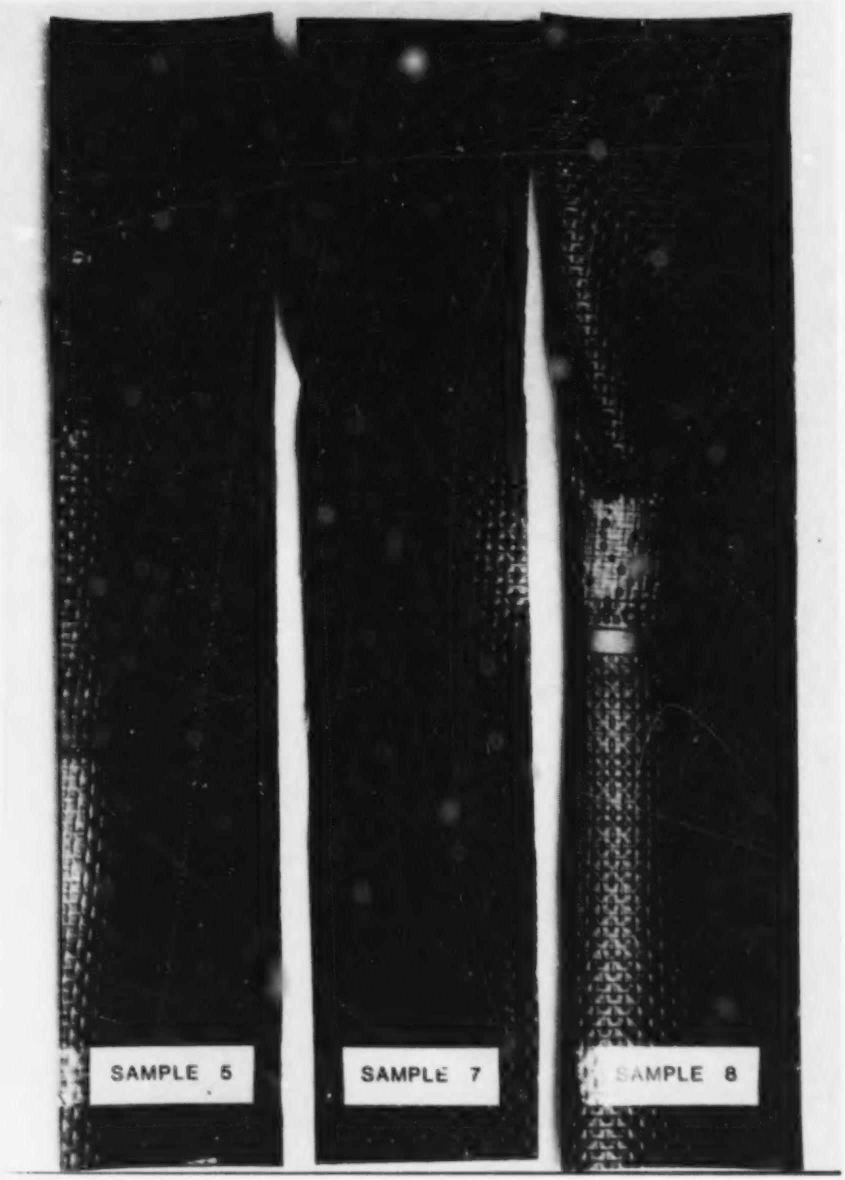


Figure 3. View of factory seam Samples 5, 7 and 8.

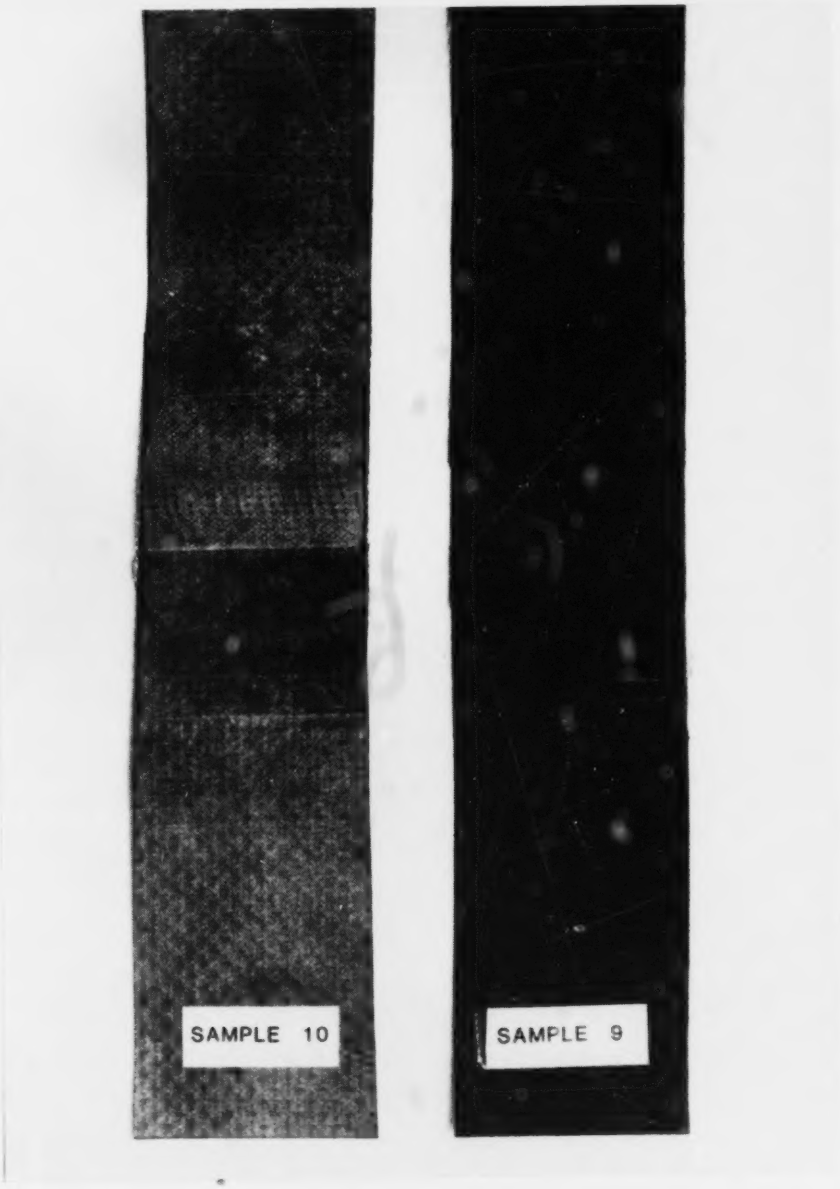


Figure 4. View of factory seam Samples 9 and 10.

Figure 5. View of factory seam Samples 14 and 15.

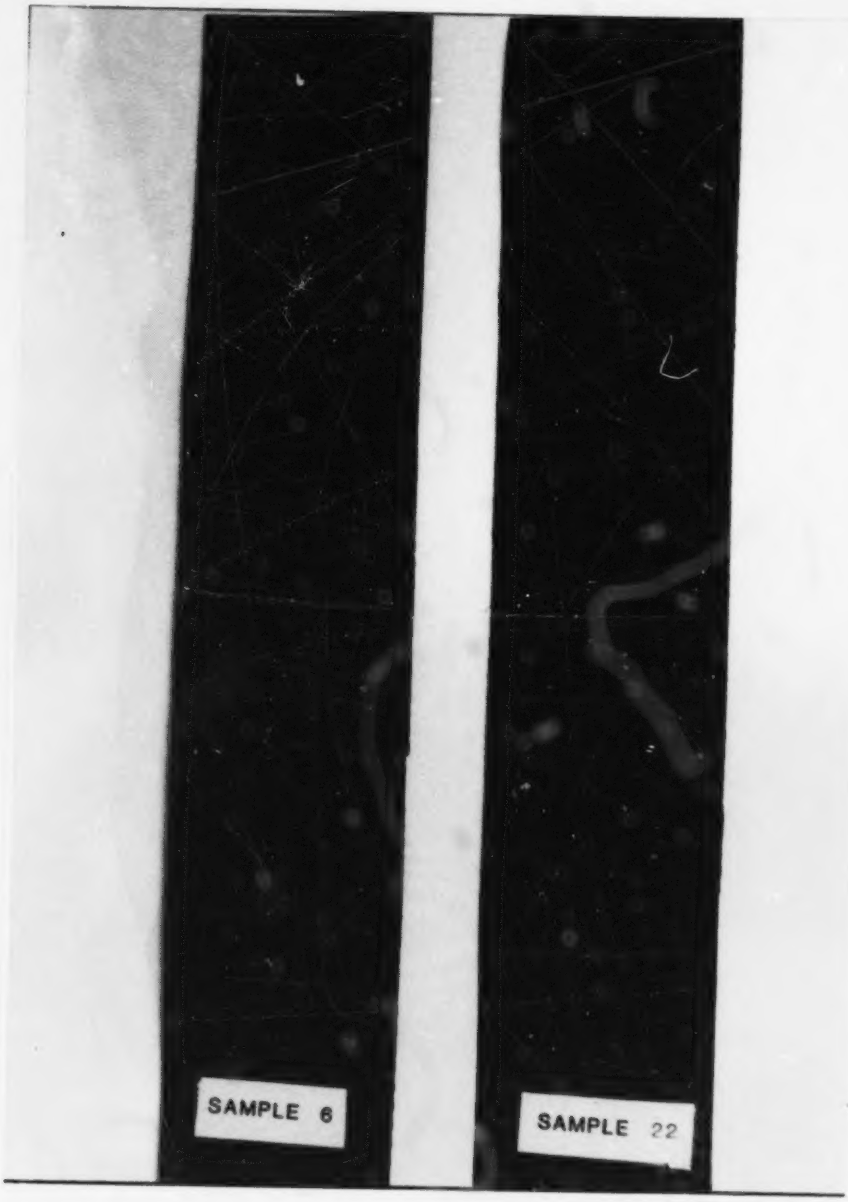


Figure 6. View of factory seam Sample 6 and field seam Sample 22.

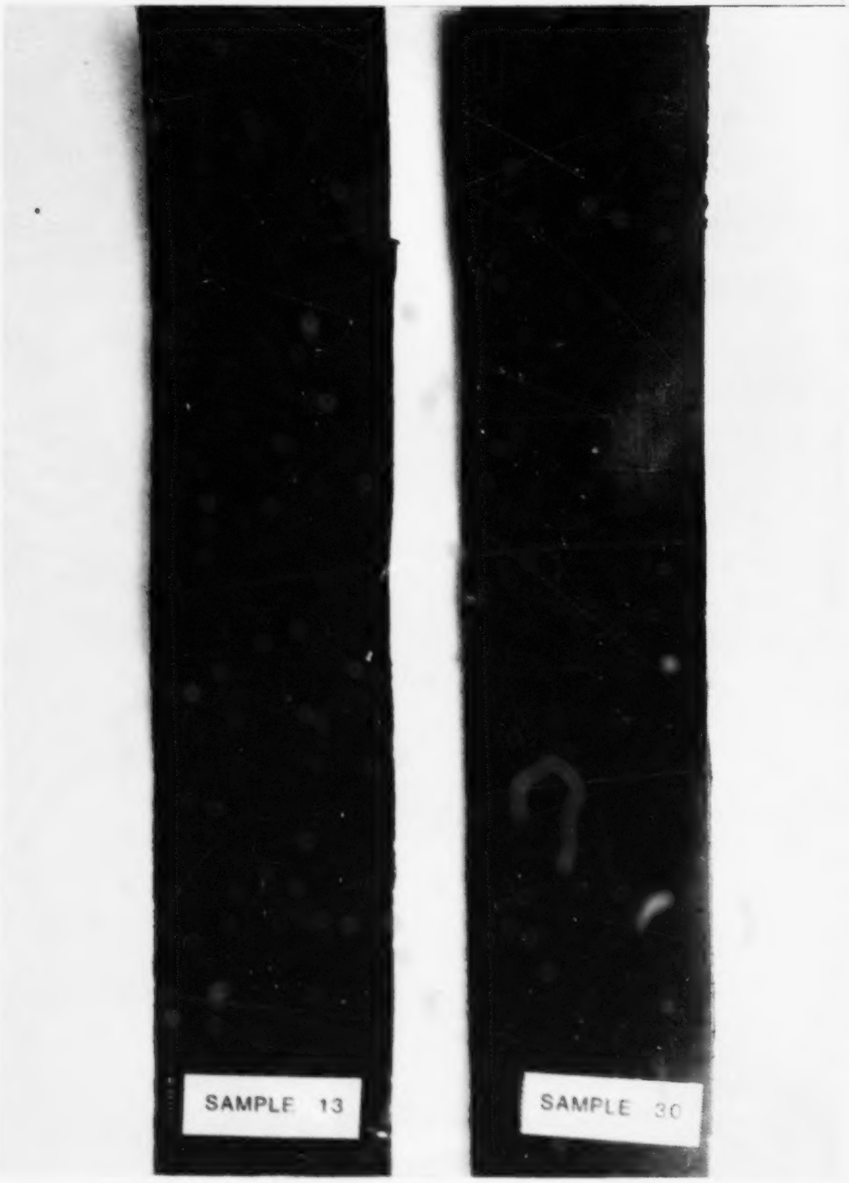
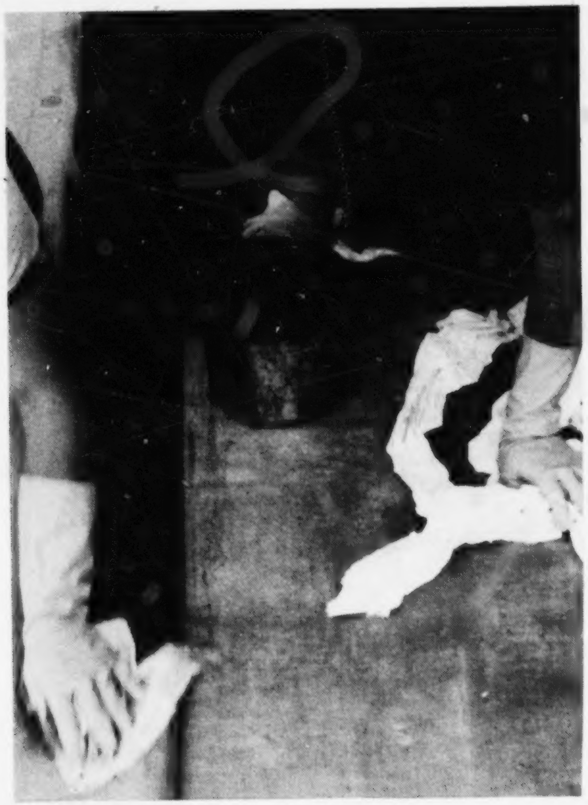


Figure 7. View of factory seam Sample 13 and field seam Sample 30.

Figure 8. View of field seam Samples 32 and 33.



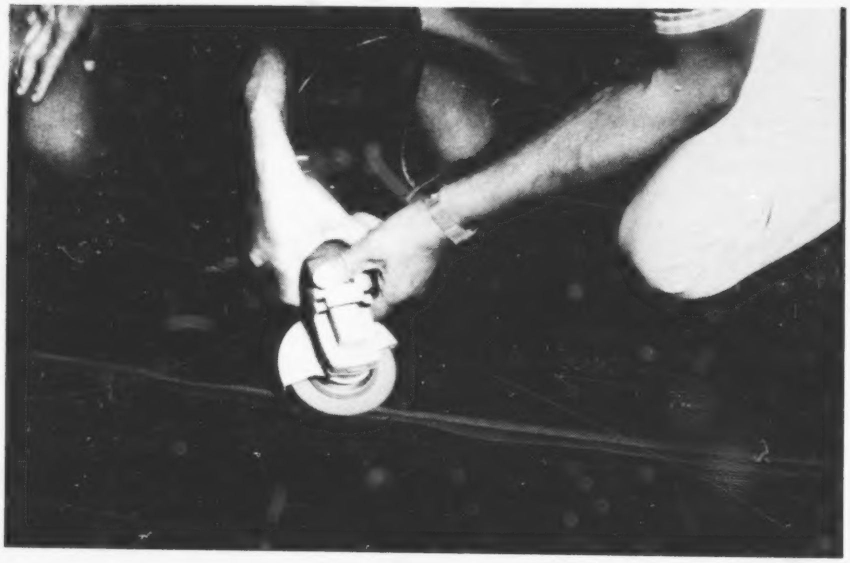
a. Cleaning of liner surface with solvent.

b. Applying bodied solvent adhesive.

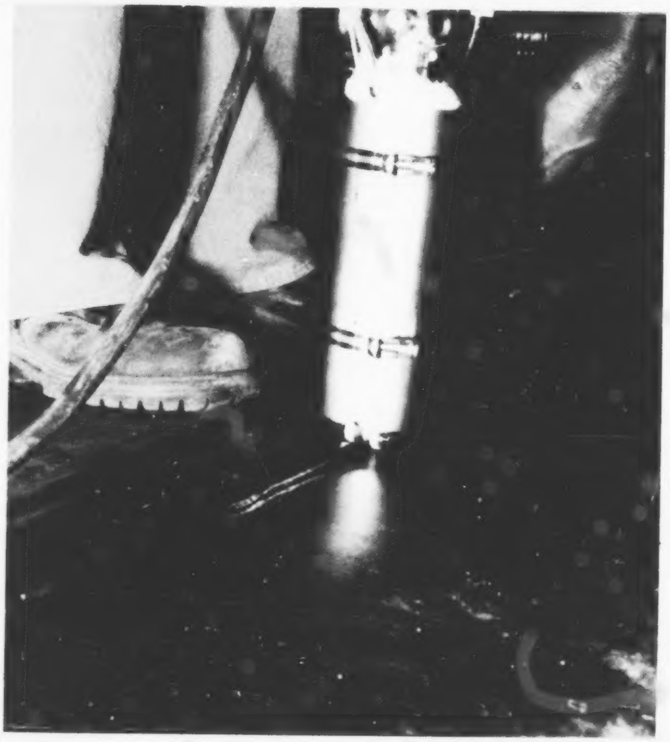
Figure 9. Typical procedures for making adhesive field seams.

c. Hand rolling field seam.

Figure 9. Typical procedures for making adhesive field seams.- Continued

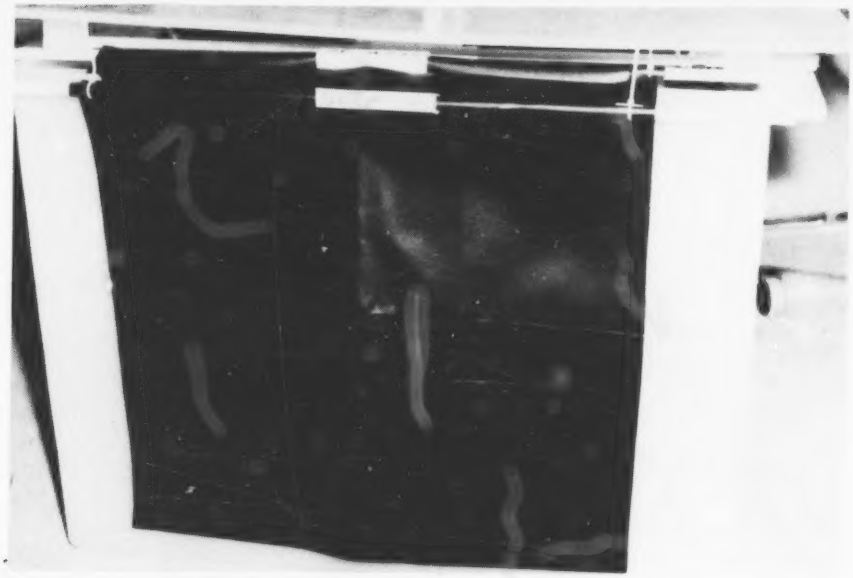


a. Grinding of HDPE liner surface prior to extrusion welding.

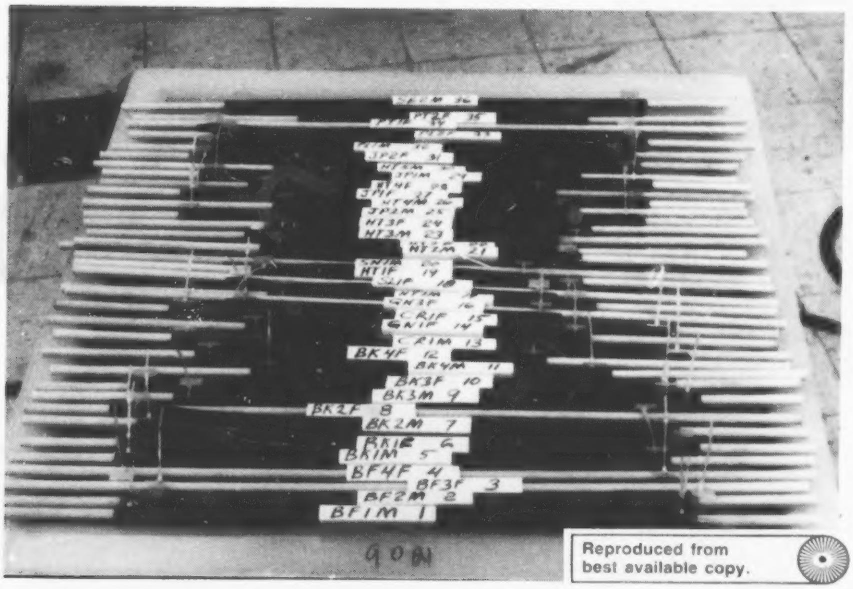


b. Extrusion welder.

Figure 10. Fillet welding of HDPE liner.



a. Factory seam samples.



Reproduced from best available copy.

b. Sample arrangement for immersion.

Figure 11. View of immersion samples.

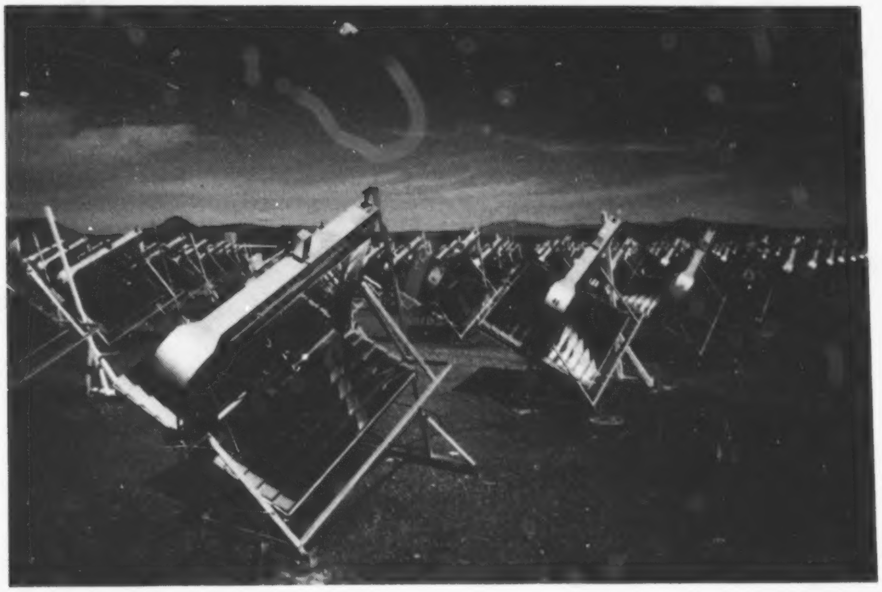
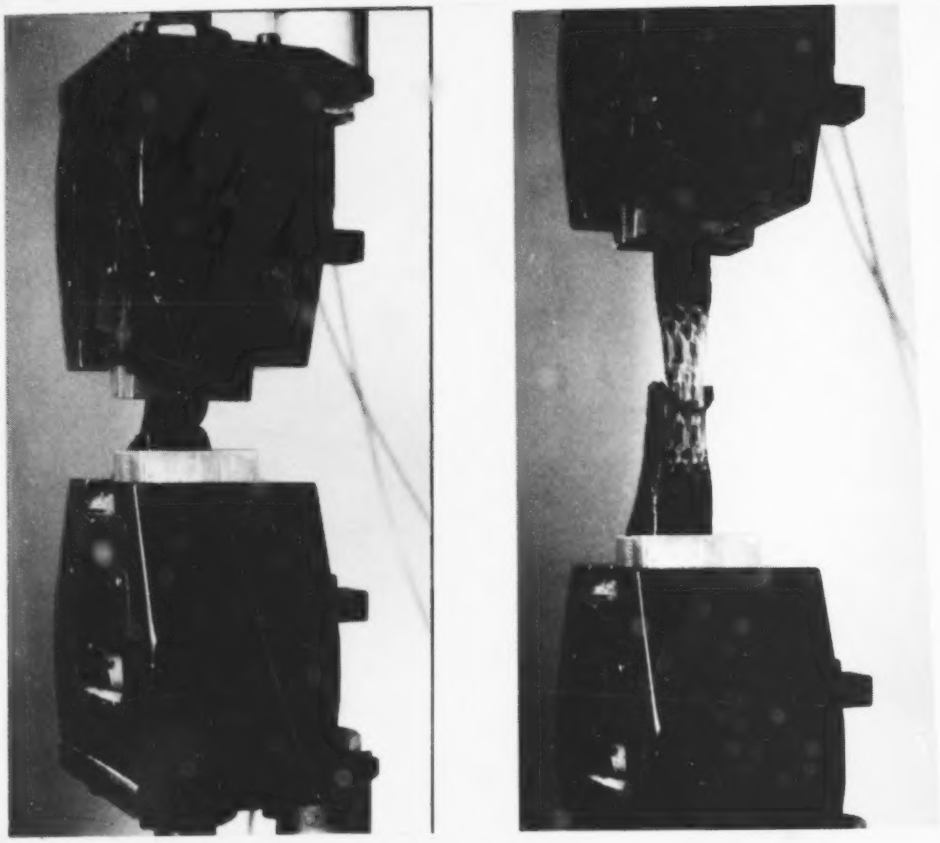


Figure 12. EMMAQUA testing machines for accelerated outdoor exposure.



a. Initial stage. b. Final stage.

Figure 13. View of dynamic peel test.

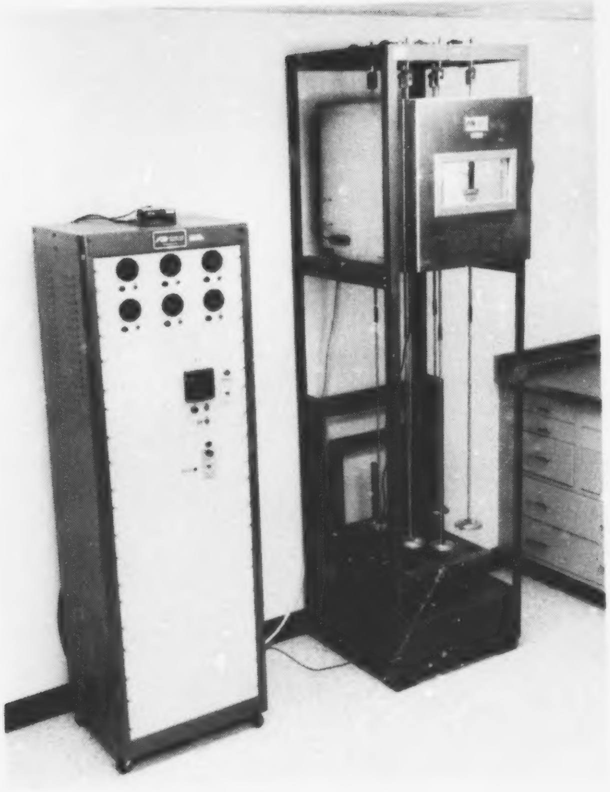


Figure 14. Static dead load test apparatus showing automated time system (left) and temperature control chamber (right).

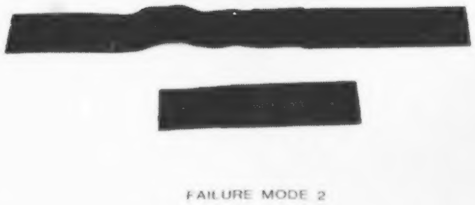


Figure 15. Failure mode 2 - parent material failure at seam edge.

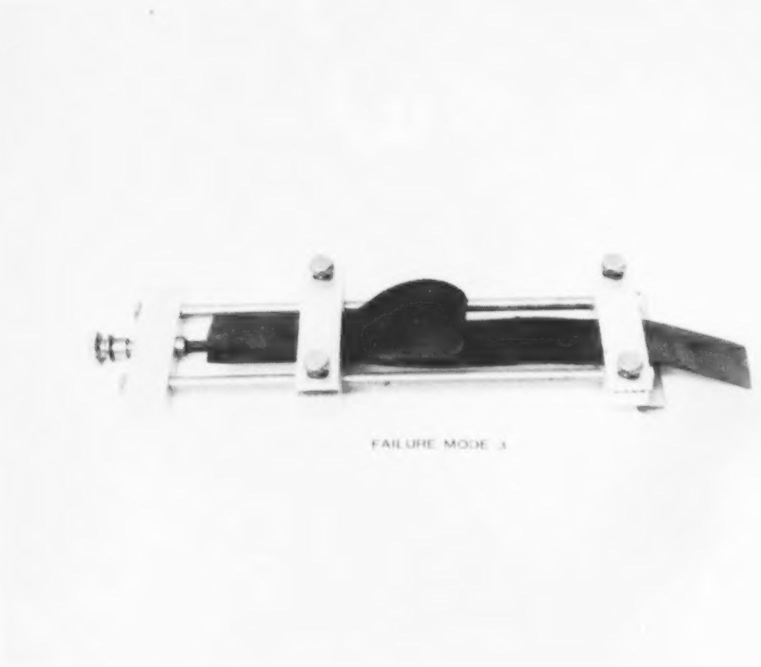


Figure 16. Failure mode 3 - within the adhesive bonding system.

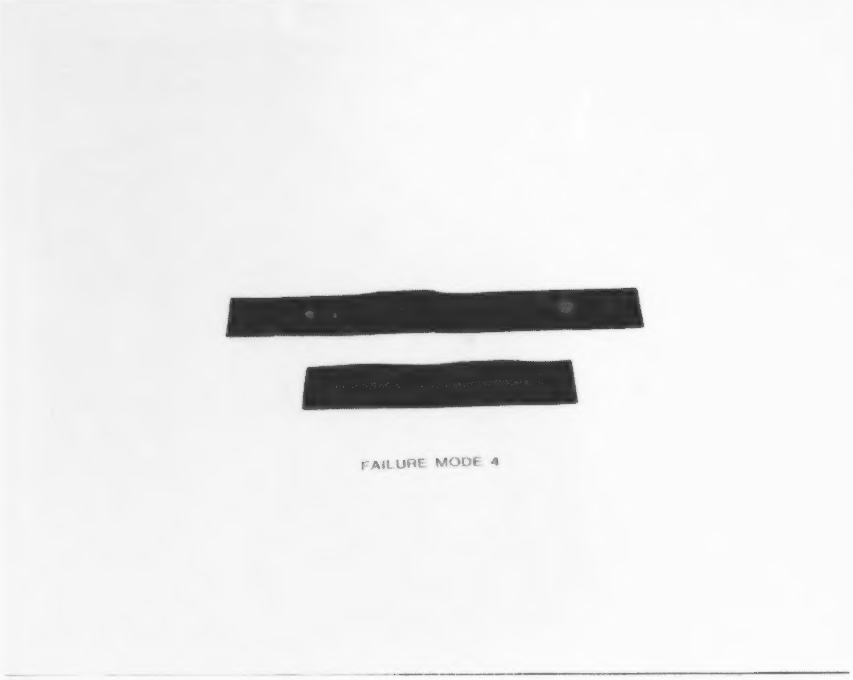


Figure 17. Failure mode 4 - planar failure between adhesive and liner surface or between two thermal-bonded surfaces.

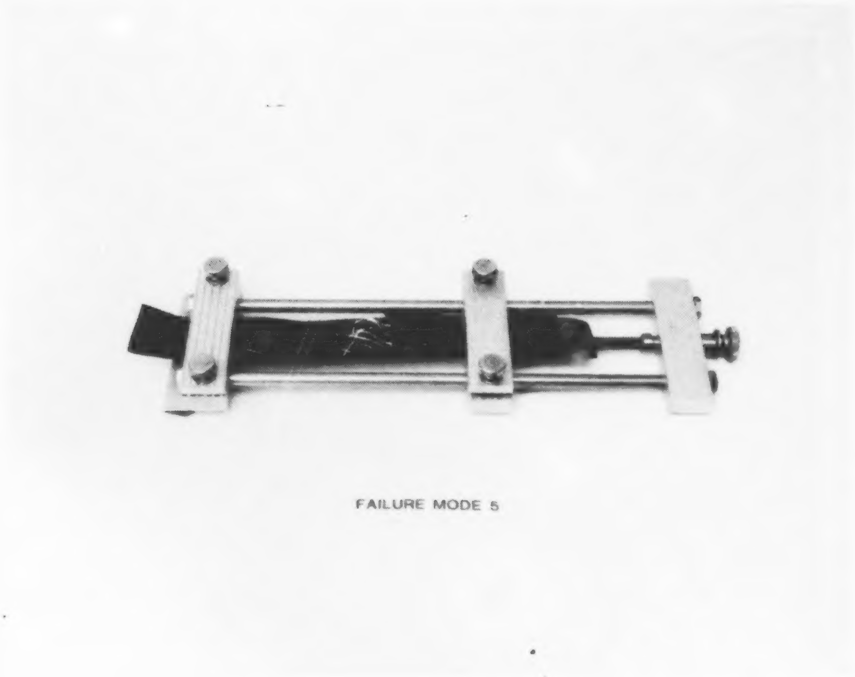


Figure 18. Failure mode 5 - scrim delamination and pullout.

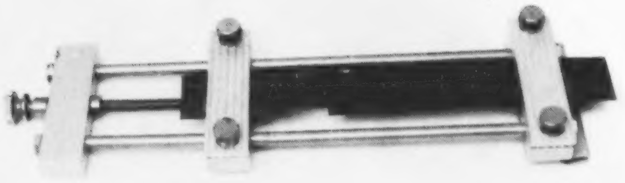


Figure 19. Failure mode 6 - failure in parent material (other than 1, 2, or 5).

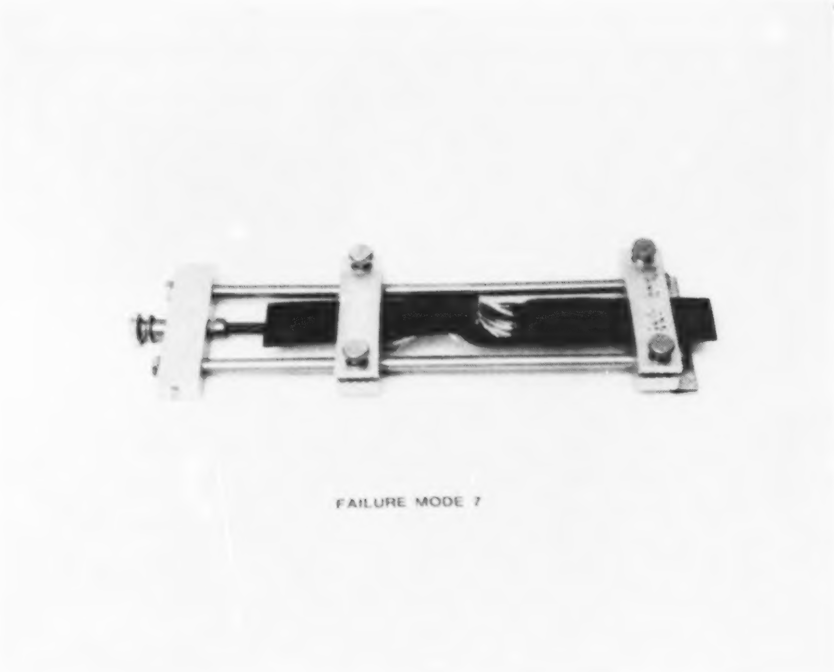


Figure 20. Failure mode 7 - scrim break within seam and subsequent pullout.

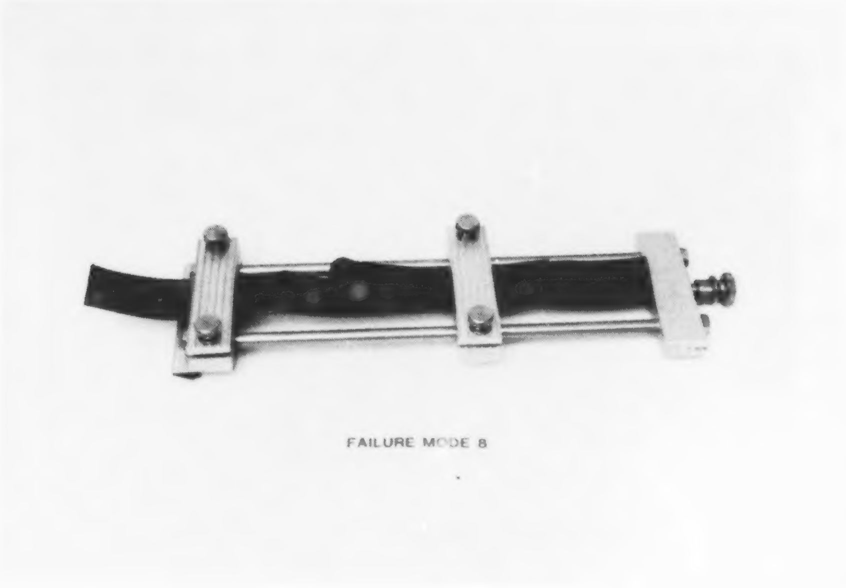


Figure 21. Failure mode 8 - ply separation. Test results are shown as initial peak load/ply adhesion.

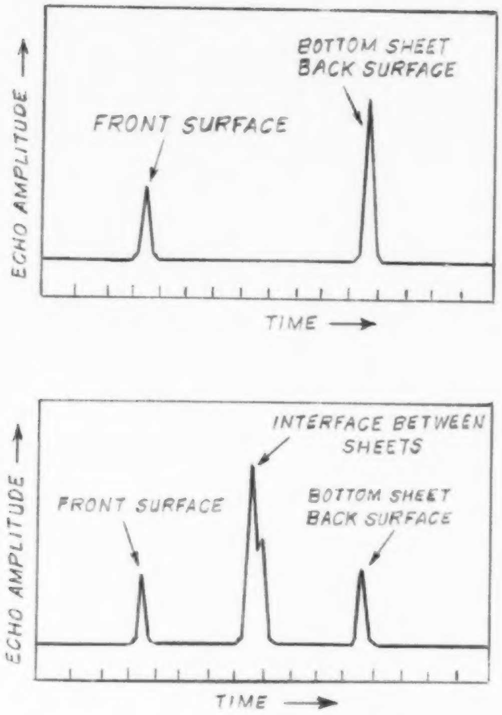


Figure 22. Sketches of a typical Pulse/Echo instrument display for a well bonded seam (top), and a faulty bond in a PVC seam (bottom).

Figure 23. View of UPE (ultrsonic pulse echo) for testing flexible membrane liner seams. See Figure 22 for CRT display.

Figure 24. View of surface transducer used in UIP (ultrasonic impedance plane) technique for testing flexible membrane liner seams.

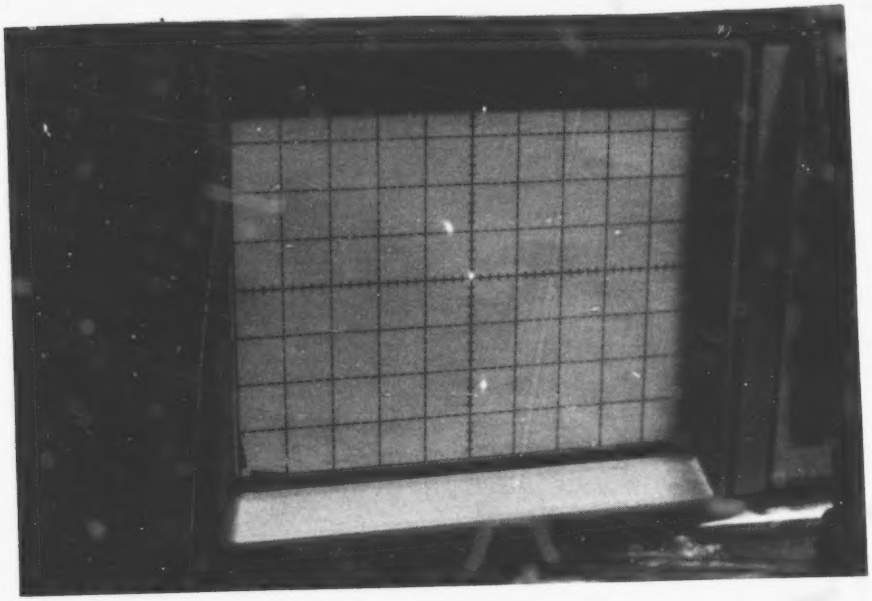


Figure 25. Calibrated UIP instrument display. Dots, from top to bottom, indicate unbond, poor bond, good bond and uncoupled calibration.

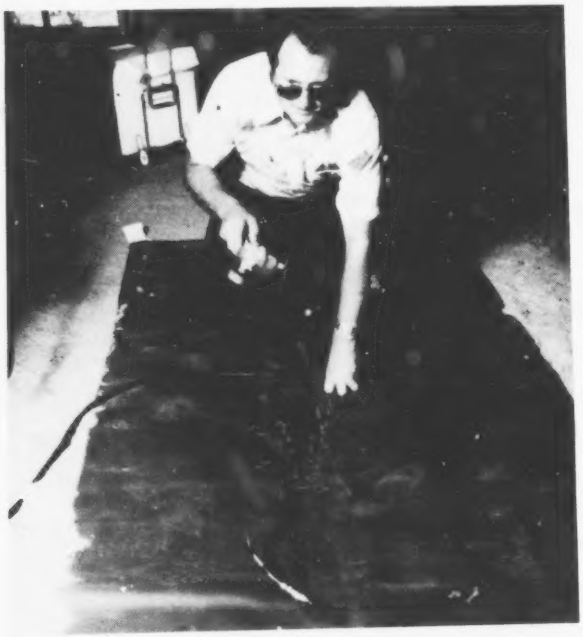


Figure 26. Air lance testing of FML seam.

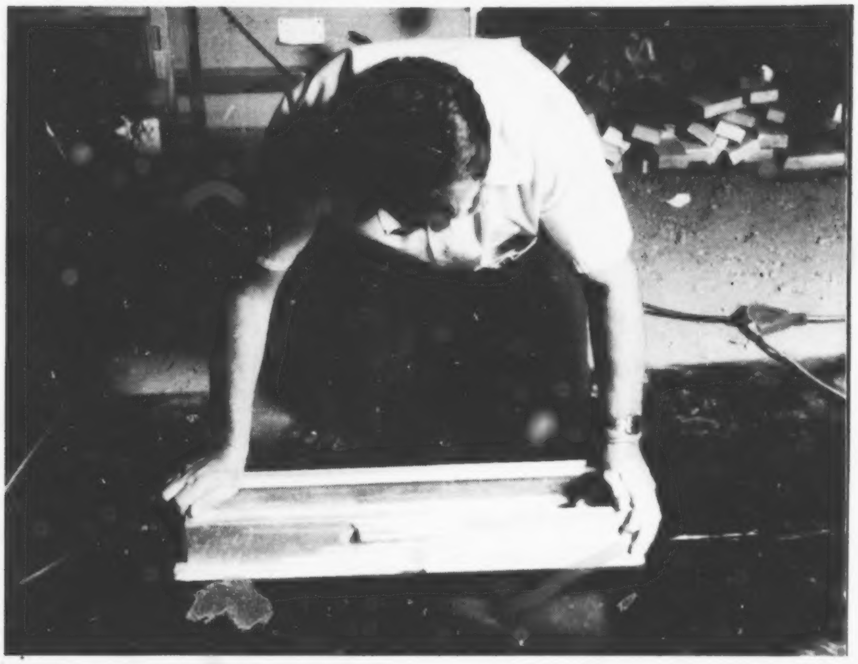


Figure 27. Vacuum testing of FML seams.

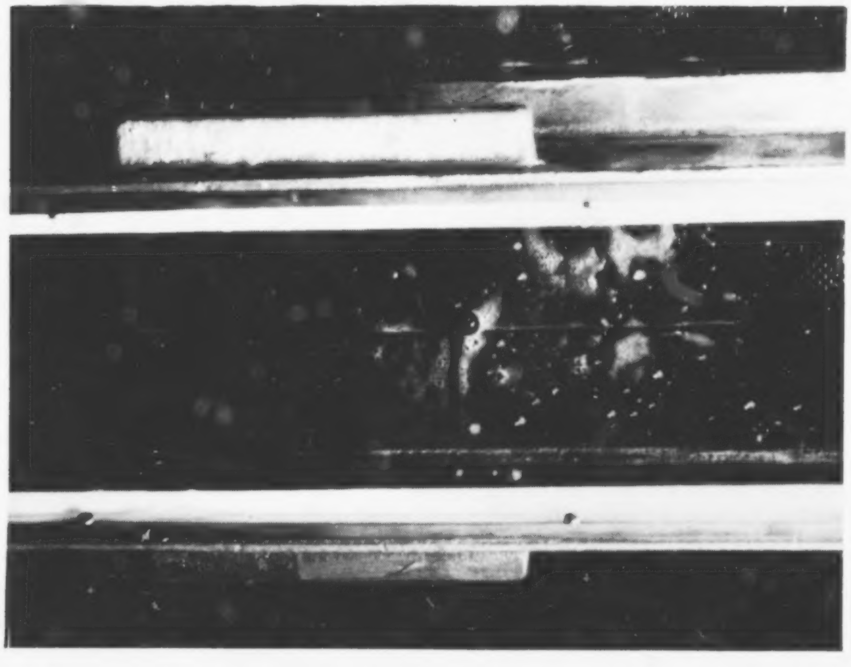


Figure 28. Close-up view of vacuum testing. Air bubble indicates unbonded seam.

SECTION 7

TEST RESULTS AND DISCUSSION

Shear and Peel Tests

Results of shear and peel tests for the 37 seam samples are summarized on figures 29 through 102 and tables 1 through 37 in the Appendix. Also listed in the tables in the appendix are the failure mode and standard deviation for the individual tests.

On the figures, a bar graph format is used to present the test data. A key to the symbols used on the figures is presented in table 11.

Two consecutive figures are used to show the seam strength for each individual sample. The first figure showing shear and the second showing peel strength. A horizontal line is used on the figures to show the original test values for the unaged material. For results of peel tests where a ply separation (failure mode 8) has occurred to the original (unaged) material, two horizontal lines are shown. The upper represents the peak load and the lower the ply adhesion value. For results on the aged materials where ply separation occurred the vertical bars are divided equally with the left portion showing the peak load and the right portion showing the ply adhesion values. This type of peel failure was generally limited to the EIA seams (samples No. 9 and 26), the EPDM vulcanized factory seam (sample No. 10), and supported CSPE materials, reinforced with a 10 by 10 scrim (samples No. 5, 7, 8, 21, 23, 24, and 25).

Test results indicate no direct correlation exists between shear and peel strength. For example, high shear strength does not guarantee high peel strength. The shear test appears to be more indicative of the strengths and weaknesses of the parent material while the peel test is more a means of determining the strengths and weaknesses of the seam bond. It is not necessary to determine whether or not the forces to be applied in the field are shear or peel or some combination of the two. For the purpose of this study, changes in seam characteristics can often be rapidly identified by the peel test. However, both are useful.

For supported FML's, the seam strength properties within the same generic group (CPE and CSPE for example) varied depending upon the particular FML chemical formulation and type of scrim reinforcement.

The most common type of failure in the shear test for the supported FML's was mode 7, scrim break within seams and subsequent pullout. For the unsuported FML's, failure at the seam edge (mode 2) was the most common occurrence in the shear test.

As mentioned above, ply separation (mode 8) was the most common type of peel failure that occurred to the supported materials reinforced with a 10 by 10 scrim. For the other supported materials, failure mode 7 was generally the most common.

Several materials from the same source were furnished with different types of factory seams. These materials include the following:

Material	Sample No.	Factory seaming method
36 mil CSPE(s)	7	Bodied solvent adhesive
36 mil CSPE(s)	8	Dielectric
30 mil CPE(u)	11	Solvent adhesive
30 mil CPE(u)	12	Dielectric
30 mil PVC(u)	14	Solvent adhesive
30 mil PVC(u)	15	Dielectric

Comparison of the two factory seaming methods for the CSPE(s) materials is shown in table 12. Results indicate that the factory seam made with the bodied solvent adhesive exhibited higher shear and peel strengths in comparison to the dielectrically made factory seam. The higher seam strength is primarily due to the wider factory seam for the chemical adhesive seam. No difference was found between the two methods in the type of shear and peel failure that occurred. Mode 7 for the shear and mode 8 for the peel.

Comparison of the factory seaming methods used for the unsupported PVC and CPE liners is shown in table 13. The factory seams made with the solvent adhesive exhibited higher shear strengths while the dielectrically made factory seams produced higher peel strength values. In the shear tests, failure occurred at the seam edge, mode 2. The same was also true for the peel tests except for the PVC solvent adhesive seam where the failure occurred within the seam, mode 4.

In addition to the comparison of some of the factory seaming methods, this study also provided an opportunity to evaluate the three commonly used methods to field seam HDPE liners. Results of the comparison (for unaged materials) are shown in table 14. Of three thermal methods, the extrusion lap weld produced the highest shear and peel strengths. The extrusion fillet weld produced a slightly higher shear strength than the hot dual wedge, but the peel strengths of these two seams were nearly identical. However, in the peel tests, the hot dual wedge seam exhibited a failure within the seam area (failure mode 4), while the other two field seams failed at the seam edge (failure mode 2).

In November 1983, NSF issued Standard No. 54, "Flexible Membrane Liners." The factory seam requirements in the standard for the materials evaluated in this study were reviewed. Based on the results of this and other Bureau studies, the shear requirements (breaking factory) are satisfactory but the peel requirements (peel adhesion) for the unsupported materials such as CPE and PVC appear to be low. The current requirement is FTB or 10 lbf/in width. Results of this study indicate that industry is capable of producing factory seams with higher peel strengths. Consequently, it is recommended that the NSF Joint Committee on FML's gives consideration to increasing the peel adhesion values for CPE and PVC.

The seam peel requirement for the supported CPE and CSPE materials is ply separation in the plane of the scrim or 10 lbf/in width. However, as previously mentioned, ply separation (mode failure 8) only occurred to the CSPE materials reinforced with a 10 by 10 scrim. Consequently, the requirement of ply separation for materials manufactured with a more open scrim (6 by 6, 8 by 8, etc.) may not be applicable. Also, the peel adhesion requirement of 10 lbf/in width appears to be low. As discussed above, consideration should also be given to increasing the peel adhesion values for supported CPE and CSPE materials.

Dead Load Testing

Results of dead load testing are summarized in table 15. For the most part there was no direct correlation between the results of this testing and the dynamic peel testing. This may be due to the fact that the same load was used in all tests, rather that a variable load depending upon the strength of the particular liner. The results did indicate that the unsupported CPE seams, both factory and field, are very susceptible to creep at elevated temperatures. Failure also occurred to the PVC/CPE composite factory seam (sample No. 16). Most of these failures occurred in the parent material rather than in the seam itself.

Companion specimens of the supported CSPE factory seam, sample No. 4, which exhibited a substantial decrease in peel strength after heat aging and 50 °C brine exposures also failed in dead load testing. Failure occurred within the seam (mode 4) rather than outside the seam (mode 7) as noted for the unaged material.

The EPDM field seam, sample No. 27, also failed under dead load testing. The failures occurred within the adhesive bonding system (mode 3). The failures of the various test specimens was primarily due to the initial low peel strength (8.6-lbf/in width) associated with this seam.

EMMAQUA Testing

The accelerated outdoor exposure testing was conducted from November 1, 1983, through October 31, 1984. During this period of time, the 32 representative seam samples were exposed to a total of 1.45 million langleys (60,648 MJ/m^2). This EMMAQUA exposure is equivalent to approximately 8 years of conventional outdoor exposure. At 6 months, 660,430 langleys (27,632 MJ/m^2), and at the completion of the exposure, the contractor inspected the samples and rated their physical appearance, based on several factors, on a scale of 1 (extremely poor condition) to 10 (as-received condition). These factors included:

- General appearance
- Delamination of seam
- Checking/crazing
- Cracking
- Blistering
- Warping

Results of the visual inspection are summarized in table 16.

Test results indicate that the 1-year EMMAQUA exposure period may be too long, resulting in accelerated weathering conditions that are too severe for some materials, thus producing erroneous results. For example, several polyolefin samples suffered severe thermal degradation from the EMMAQUA exposure. The 80-mil HDPE extrusion lap-welded field seam, sample No. 32, had melted to such a condition that it was not possible to conduct peel tests on the seam. Also, the LLDPE field seam, sample No. 34, contained two areas where the material appeared to have melted as shown in figure 103.

Based on the visual inspection, the thermal degradation occurred between 6 and 12 months of exposure. Consequently, some additional studies are recommended to determine if the EMMAQUA exposure is truly representative of long-term weathering for FML's. It should be noted that NSF, in certifying new exposed FML's, requires both the membrane and factory seam to pass a weathering test (EMMAQUA exposure) of a minimum of 1,000,000 langleys with a rating of 7 or better. The rating criteria are described in appendix A, part 9 of reference 4. Under the EMMAQUA exposure, the 1,000,000 langleys can be achieved in approximately 8 months.

Weight and Thickness Measurements

Weight. - Results of weight measurements for the 21 coupon samples listed in table 5 are summarized in table 14 and shown grapically on figures 104 to 124. Failure of a coupon sample is indicated by the numerical value - 100 in both the figures and tables. Results were those expected for the type of FML and chemical exposure.

Weight changes for the supported CPE and CSPE materials varied depending upon the particular liner formulation. The CPE(s) materials experienced the largest weight gains from immersion in the furfural solution. Immersion in phenol and furfural produced the largest weight gains for the CSPE(s) materials. The EIA material exhibited its largest weight gain from immersion in furfural. A slight weight loss was noted for the sample immersed in NaOH. Immersion in furfural produced the largest weight gain for the EPDM material.

For the unsupported materials, CPE exhibited a very large weight gain from immersion in furfural. A weight increase of over 100 percent was noted after 8 weeks of immersion. After this period of time, the percent weight gain decreased but there was some variation in the test results. A weight increase of over 40 percent was noted after 1 week of immersion in phenol. Subsequent measurements showed a gradual decrease in the weight gain. Immersion in methyl ethyl ketone produced a gradual increase in weight.

The PVC materials experienced weight losses from immersion in sodium hydroxide and phenol. A significant increase of over 50 percent weight gain occurred after only 1 week of immersion in furfural. Subsequent measurements showed a gradual decrease in the weight gain.

The polyolefin materials showed very little weight change except for those immersed in methylene chloride. The weight gain ranged from 4 to 7 percent.

Thickness. - Results of thickness measurements are summarized in table 18. As with the weight measurements, failure of a coupon sample is indicated by the numerical value - 100.

The thickness measurements generally paralleled the results of the weight measurements for the water and brine samples. However, the results for the chemical immersion samples varied primarily due to the various degrees of swelling.

Table 11. Key to symbols for figures 29 to 102

Exposure	Symbol	1st time interval	2d time interval	3d time interval
Water	H_2O	3 months	6 months	12 months
23 °C Brine	B23	3 months	6 months	12 months
50 °C Brine	B50	3 months	6 months	12 months
Phenol	PHE	3 months	6 months	12 months
Hydrochloric acid	HCL	3 months	6 months	12 months
Sodium hyroxide	NOH	3 months	6 months	12 months
Methyl ethyl ketone	MEK	3 months	6 months	12 months
Methylene chloride	MCL	3 months	6 months	12 months
Furfural	FUR	3 months	6 months	12 months
Heat aging	HA	4 weeks	8 weeks	13 weeks
Freeze/thaw cycling	F/T	10 cycles	20 cycles	50 cycles
Wet/dry cycling	W/D	10 cycles	20 cycles	50 cycles
EMMAQUA	EMA	-	-	12 months

Table 12. Comparison of factory seaming methods for supported 36-mil CSPE (10 by 10 polyester scrim) liners

Seaming method	Seam width (in)	Breaking strength (lbf/in)	Seam shear strength (lbf/in)	Seam peel strength (lbf/in)
Bodied solvent adhesive	3.00	165.0	91.8	34.4/17.7
(failure mode)			(7)	(8)
Dielectric	1.25	165.0	73.5	30.9/11.4
(failure mode)			(7)	(8)

* Breaking strength of parent material
Note: lbf/in = 175.1 N/m
1 in = 25.4 mm

Table 13. Comparison of factory seaming methods for unsupported PVC and CPE liners

Seaming method	30-mil PVC(u)				30-mil CPE(u)			
	Seam width (in)	Breaking strength* (lbf/in)	Seam shear strength (lbf/in)	Seam peel strength (lbf/in)	Seam width (in)	Breaking strength* (lbf/in)	Seam shear strength (lbf/in)	Seam peel strength (lbf/in)
Solvent adhesive (failure mode)	1.00	60.0	57.2 (2)	14.8 (4)	1.00	53.0	42.0 (2)	21.3 (2-6)
Dielectric (failure mode)	0.75	60.0	52.9 (2)	38.1 (2)	0.75	53.0	33.1 (2)	29.6 (2)

* Breaking strength of parent material

Note: lbf/in = 175.1 N/m
1 in = 25.4 mm

Table 14. Comparison of field seaming methods for 80-mil HDPE liners

Seaming method (thermal)	Seam width (in)	Maximum strength* (lbf/in)	Seam shear strength (lbf/in)	Seam peel strength (lbf/in)
Extrusion fillet weld	-	241	203	123
(failure mode)			(9-2)	(2)
Extrusion lap weld	1.75	230	242	175
(failure mode)			(9)	(2)
Hot dual wedge	1.00	221	224	121
(failure mode)			(9)	(4)

* Maximum strength of parent material

Note: lbf/in = 175.1 N/m
1 in = 25.4 mm

TABLE 15. RESULTS OF DEAD LOAD TESTING

SAMPLE NUMBER		ORIGINAL	H2O			23° BRINE		50° BRINE		PHENOL		HCL		NAOH	
		0	3	6	12	3	12	6	12	6	12	6	12	6	12
1	CPE-S	F 4	P	F 5	P	P	P	P	P	F 7	--	P	P	P	P
2	CPE-S	P	P	P	F 4	P	P	F 4	F 4	F 2-4	P	P	P	P	--
3	CSPE-S	F 4	F 4	P	P	F 4	P	P	P	F 4	P	F 4	P	P	P
4	CSPE-S	P	P	P	P	P	P	F 4	F 4	P	P	P	P	P	P
5	CSPE-S	P	P	P	P	P	P	P	P	F 9	P	P	P	P	P
6	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
7	CSPE-S	P	F 4	P	F 3	P	F 3	P	P	F 4	P	P	P	F 3	F 3
8	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
9	EIA-S	P	P	P	--	P	--	P	P	P	P	P	P	P	P
10	EPDM-S	P	--	P	P	P	P	P	P	P	P	P	P	P	P
11	CPE-U	F 2	F 3	F 2	F 4	F 2	F 6	P	F 6	F 4	F 3	F 2	F 2	--	P
12	CPE-U	F 2	F 6	F 2	F 6	F 6	F 2	F 2	F 6	F 2	F 2	F 2	F 2	P	F 2
13	LLDPE-U	P	P	P	P	P	P	P	P	P	P	P	P	P	P
14	PVC-U	P	P	P	P	P	P	P	P	P	P	P	P	P	P
15	PVC-U	P	P	P	P	P	P	P	P	P	P	P	P	F 2	P
16	PVC/CPE	F 2	F 2	F 2	F 2	F 6	F 2	F 2	F	F 2	F 2	F 2	F 2	F 2	F 2
17	CPE-S	P	--	P	P	P	P	P	P	P	P	P	P	P	P
18	CPE-S	P	P	P	P	P	P	F 3	F 3	F 4	F	F 3	P	F 3	--
19	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
20	CSPE-S	P	P	P	P	P	P	F 3	F 3	P	P	P	P	P	P
21	CSPE-S	P	--	P	P	P	P	P	P	P	P	P	P	P	P
22	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
23	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
24	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
25	CSPE-S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
26	EIA-S	P	P	P	--	P	P	P	P	P	P	P	P	P	P
27	EPDM-S	F 4	--	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3
28	CPE-U	F 2	F 3	F 2	F 4	F 2	F 6	F 2	F 6	F 4	F 3	F 2	F 2	F	P
29	CPE-U	F 2	F 3	F 3	F 4	F 2	F 6	F 3-6	F 6	F 4	F 3	P	F 6	P	P
30	HDPE-U	P	P	P	P	P	P	P	P	P	P	P	P	P	P
31	HDPE-U	P	P	P	P	P	P	P	P	P	P	P	P	P	P
32	HDPE-U	P	P	P	P	P	P	P	P	P	P	P	P	P	P
33	HDPE-U	P	P	P	P	P	P	F 2	P	P	P	P	P	P	P
34	LLDPE-U	P	P	P	P	P	P	P	P	P	P	P	P	P	P
35	PVC-U	P	P	P	--	P	--	F 4	F 3	P	P	P	P	P	F 4
36	PVC-U	P	P	P	F 4	P	P	P	F 3	P	P	P	P	P	P
37	PVC-U	P	P	P	--	P	--	P	P	P	P	P	P	P	P

TABLE 15. RESULTS OF DEAD LOAD TESTING (continued)

SAMPLE NUMBER	MEK		MCL		FURFURAL		HEAT AGING			FREEZE/THAW			WET/DRY		
	6	12	6	12	6	12	4	8	13	10	20	50	10	20	50
1	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
2	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
3	P	P	--	--	P	P	P	P	P	P	P	P	F 4	P	P
4	P	P	--	--	P	P	F 4	F 4	F 4	P	P	P	P	P	P
5	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
6	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
7	P	P	--	--	P	P	P	P	P	P	P	P	P	P	F 4
8	P	F 3	--	--	P	P	P	P	P	P	P	P	P	P	P
9	P	--	--	--	F 4	--	P	P	P	P	P	P	P	P	P
10	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
11	F 2	F 2	--	--	F 4	F 3	F 6	P	F 2	F 9-6	F 9-1	F 9-1	F 2-6	F 9	F 1-2
12	F 2	F 1	--	--	F 2	F 2-6	F 2	F 9	F 2	F 6	F 2	F 2	F 6	F 9	F 2
13	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
14	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
15	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
16	F 2	F 2	--	--	F 2	--	F 2	F	F 2	F 2	F 2	F 6	F 2	F 2	F 2
17	P	P	--	--	P	P	P	P	F 4	P	P	P	P	P	P
18	F 3	P	--	--	P	P	F 3	P	F 4	P	F 4	P	P	P	P
19	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
20	P	P	--	--	P	P	F 3	F 4	P	P	P	P	P	P	P
21	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
22	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
23	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
24	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
25	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
26	P	F	--	--	P	P	P	P	P	P	P	P	P	P	P
27	F 3	--	--	--	F 3	--	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3	F 3
28	F 2	--	--	--	F 4	F 3	F 6	F 9	F 6-2	F 6	F 6	F 9-6	F 6	F 9	F 6
29	F 2	F 2	--	--	F 3	F 3-4	P	P	F 9-4	F 4	F 9-4	F 9-4	F 3	F 4	F 9-4
30	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
31	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
32	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
33	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
34	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
35	P	P	--	--	P	P	P	F 4	P	P	P	P	P	P	F 4
36	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P
37	P	P	--	--	P	P	P	P	P	P	P	P	P	P	P

Table 16. Results of visual inspection for EMMAQUA samples (continued)

Sample No.	Material	General appearance		Delamination of seam		Checking/ crazing		Cracking		Blistering		Warping		Remarks
		6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	
1	36 mil CPE(s)	8	6	9	8	10	10	10	10	9	7	8	7	Some blisters inside seam area at 6 months.
2	36 mil CPE(s)	9	9	10	10	10	10	10	10	10	10	9	9	
5	36 mil CSPE(s)	9	8	10	10	10	10	10	10	10	10	9	8	
6	36 mil CSPE(s)	7	6	9	8	10	10	10	10	8	7	7	5	Several blisters inside seam area were noted at 6 months, Sample was stiff
7	36 mil CSPE(s)	9	7	10	8	10	10	10	10	10	8	9	8	Some blisters inside seam area at 12 months.
8	36 mil CSPE(s)	9	9	10	10	10	10	10	10	10	10	9	9	
9	38 mil EIA(s)	9	8	10	10	10	10	10	10	10	10	9	8	Sample was stiff.
10	30 mil EPDM(s)	9	9	10	10	10	10	10	10	10	10	9	9	
11	30 mil CPE(u)	8	7	10	10	10	9	10	10	10	10	8	7	
12	30 mil CPE(u)	8	7	10	10	9	6	10	7	10	10	8	6	Sample was stiff.
13	30 mil LLDPE(u)	7	4	10	10	10	7	9	6	10	10	8	4	At 12 months sample contained two places where it appears to have melted.
14	30 mil PVC(u)	8	7	10	10	9	7	10	10	10	10	8	7	
15	30 mil PVC(u)	9	9	10	10	10	10	10	10	10	10	8	8	

16. Results of Visual inspection for EMMAQUA samples (continued)

Sample No.	Material	General appearance		Delamination of seam		Checking/ crazing		Cracking		Blistering		Warping		Remarks
		6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	
16	30 mil PVC/CPE(u)	8	7	10	10	10	10	10	10	10	10	8	6	Sample was stiff.
17	36 mil CPE(s)	8	8	9	8	10	8	10	10	9	8	9	8	Some blisters inside seam area at 6 months. Sample was stiff.
18	36 mil CPE(s)	7	7	10	10	10	10	10	10	10	10	9	9	Mottled blue appearance at 6 months. Sample was stiff.
21	36 mil CSPE(s)	9	8	10	10	10	10	10	10	10	10	9	8	Sample was stiff.
22	36 mil CSPE(s)	8	7	9	8	10	8	10	10	8	7	8	7	Several blisters inside seam area were noted at 6 months. Sample was stiff.
23	36 mil CSPE(s)	9	7	9	8	10	10	10	10	9	8	9	8	Some blisters inside seam area at 6 months.
24	36 mil CSPE(s)	8	8	9	9	10	10	10	10	9	8	9	9	Some blisters inside seam area at 6 months.
25	36 mil CSPE(s)	9	9	10	10	10	10	10	10	10	10	9	9	
26	38 mil EIA(s)	9	9	10	10	10	10	10	10	10	10	9	9	
27	30 mil EPDM(s)	9	8	10	9	10	10	10	10	10	10	9	8	
28	30 mil CPE(u)	8	7	10	8	10	10	10	10	10	7	8	8	Several blisters inside seam area at 12 months.
29	30 mil CPE(u)	9	6	10	10	10	4	10	10	10	10	8	7	Sample was stiff.
30	30 mil HDPE(u)	8	7	8	8	10	10	10	10	10	10	8	5	Sample was brittle.

Table 16. Results of visual inspection for EMMAQUA samples (continued)

Sample No.	Material	General appearance		Delamination of seam		Checking/ crazing		Cracking		Blistering		Warping		Remarks
		6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	6 mo	12 mo	
32	80 mil HDPE(u)	8	5	10	10	10	9	10	10	10	10	8	8	Sample was very brittle and contained large area which appears to have melted.
33	80 mil HDPE(u)	9	4	9	7	10	5	10	[illegible]	10	10	8	6	Sample was very brittle.
34	30 mil LLDPE(u)	9	4	9	7	10	5	10	[illegible]	10	10	8	6	Sample was very brittle and contained two holes from melting.
35	30 mil PVC(u)	8	7	10	10	10	10	10	10	10	10	8	8	Sample was stiff. It contained a large area with a popcornlike appearance under 20X magnification.
36	30 mil PVC(u)	9	9	10	10	10	10	10	10	10	10	8	8	Sample was stiff.
37	30 mil PVC(u)	5	3	10	10	5	3	8	8	10	10	8	7	Sample was very brittle with a sandpaper texture on bottom side. Same appearance as sample 35 under 20X magnification.

Key to rating system:

10 as received	5 fair to poor
9 excellent	4 poor
8 good	3 poor to very poor
7 good to fair	2 very poor
6 fair	1 extremely poor

TABLE 17. PERCENT CHANGE IN WEIGHT AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
A	36 MIL CPE (S)	1	4.98	1.80	1.96	38.22	1.27	2.28	18.61	230.25	28.56
		2	6.68	1.97	1.99	41.65	2.25	2.40	19.26	-100.00	34.43
		3	8.18	2.04	2.35	45.66	1.57	1.96	22.02	-100.00	38.81
		4	9.47	2.07	2.34	41.58	1.25	2.74	22.27	-100.00	40.02
		8	12.69	2.18	2.27	40.56	1.48	3.04	23.59	-100.00	45.93
		12	14.32	2.28	2.59	38.30	2.28	4.03	28.89	-100.00	47.48
		24	18.85	2.26	2.98	36.51	4.22	6.05	29.04	-100.00	45.68
		52	22.10	2.37	3.09	37.11	9.47	8.25	18.25	-100.00	47.81
B	36 MIL CPE(S)	1	2.30	1.06	1.12	14.12	0.87	1.01	16.06	-100.00	31.22
		2	3.06	1.21	1.07	12.62	1.59	0.93	16.48	-100.00	31.18
		3	3.75	1.27	1.16	11.03	0.66	0.29	16.26	-100.00	29.27
		4	4.39	1.29	0.99	10.34	0.81	-0.05	15.80	-100.00	29.62
		8	6.11	1.29	0.89	8.76	0.76	-1.51	14.19	-100.00	36.17
		12	6.98	1.35	0.68	8.45	0.76	-2.77	16.30	-100.00	18.31
		24	8.72	1.24	0.59	6.93	0.53	-4.89	13.72	-100.00	21.53
		52	9.27	1.20	0.48	6.10	-0.22	-5.37	12.72	-100.00	24.92
C	30 MIL CSPE (S)	1	1.08	0.55	0.67	9.57	-3.62	1.00	5.28	188.81	8.66
		2	1.33	0.56	0.64	10.50	1.22	0.84	5.11	-100.00	8.96
		3	1.52	0.57	0.66	10.70	0.13	0.81	5.08	-100.00	9.53
		4	1.65	0.60	0.66	10.40	-0.13	0.80	4.78	-100.00	9.81
		8	2.03	0.62	0.79	11.09	-0.08	1.06	4.07	-100.00	10.59
		12	2.24	0.71	0.81	11.79	-0.04	0.86	5.14	-100.00	10.05
		24	2.88	0.60	1.10	14.26	0.09	0.86	4.39	-100.00	11.81
		52	4.06	0.65	1.74	14.53	0.60	1.20	4.60	-100.00	14.99
D	36 MIL CSPE (S)	1	2.06	1.43	1.99	18.82	2.08	1.27	7.90	192.58	11.87
		2	2.54	1.61	2.17	19.05	2.92	1.79	7.10	59.10	14.24
		3	2.88	1.64	2.75	18.26	1.59	2.19	8.65	108.56	16.85
		4	3.17	1.75	2.85	17.92	1.25	2.05	8.74	17.98	18.81
		8	3.95	1.87	3.20	17.19	1.41	2.27	9.00	-100.00	22.22
		12	4.42	1.97	3.45	17.06	1.56	2.25	12.34	-100.00	21.20
		24	5.93	2.03	4.02	16.76	2.09	2.19	13.11	-100.00	21.66
		52	8.10	2.23	4.45	16.54	2.90	2.25	16.01	-100.00	23.89
E	36 MIL CSPE (S)	1	2.87	2.41	2.71	12.89	2.41	2.08	8.66	130.85	11.09
		2	3.32	2.75	2.83	14.53	2.68	3.17	7.52	-100.00	11.96
		3	3.52	2.77	3.07	14.63	2.43	2.94	8.09	-100.00	12.46
		4	3.65	2.84	3.07	14.86	2.31	3.00	7.70	-100.00	12.80
		8	4.02	2.84	3.19	15.32	1.87	3.18	6.81	-100.00	14.07
		12	4.14	2.97	3.31	15.78	1.95	2.94	8.06	-100.00	13.02
		24	4.74	2.88	3.93	16.66	2.61	2.56	7.07	-100.00	14.67
		52	5.81	3.00	4.46	17.54	2.68	2.15	7.25	-100.00	18.09

TABLE 17. PERCENT CHANGE IN WEIGHT AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
F	36 MIL CSPE (S)	1	1.97	1.20	1.24	16.26	0.12	1.73	7.01	203.05	9.64
		2	2.40	1.19	1.25	19.81	0.74	0.16	6.80	-100.00	10.30
		3	2.77	1.23	1.38	21.55	0.46	1.07	7.36	-100.00	12.11
		4	3.05	1.20	1.38	23.80	-0.20	1.47	7.18	-100.00	13.07
		8	3.80	1.19	1.48	29.18	0.04	1.83	7.05	-100.00	18.43
		12	4.19	1.43	1.92	32.59	0.47	1.90	8.86	-100.00	19.05
		24	5.41	1.21	2.60	38.10	1.79	2.25	9.01	-100.00	29.13
		52	6.77	1.27	3.29	38.04	6.04	3.60	10.19	-100.00	38.55
G	36 MIL CSPE (S)	1	2.75	2.11	2.25	13.91	2.01	2.22	10.29	65.08	12.95
		2	3.29	2.34	2.16	14.03	2.09	2.85	5.56	143.61	12.88
		3	3.52	2.35	2.38	13.60	1.97	2.79	6.82	54.76	13.14
		4	3.74	2.38	2.38	13.82	1.99	3.32	6.57	-15.17	13.50
		8	4.16	2.45	2.46	14.02	2.18	6.01	5.94	-100.00	17.04
		12	4.00	2.56	2.44	14.08	2.79	7.66	6.78	-100.00	13.00
		24	4.69	2.47	2.59	14.64	4.79	15.63	5.97	-100.00	14.60
		52	4.92	2.46	2.96	16.64	9.15	14.05	6.30	-100.00	17.43
H	36 MIL CSPE (S)	1	2.67	2.09	2.18	13.68	1.77	2.58	6.97	-100.00	13.09
		2	3.19	2.27	2.10	13.54	1.75	2.69	6.90	-100.00	12.98
		3	3.44	2.32	2.34	13.47	1.48	2.50	6.76	-100.00	13.29
		4	3.64	2.37	2.37	13.46	1.58	2.77	6.54	-100.00	13.61
		8	4.06	2.38	2.43	13.83	1.53	4.43	5.99	-100.00	17.40
		12	4.12	2.49	2.33	14.06	1.57	5.74	6.80	-100.00	12.85
		24	4.76	2.46	2.56	14.65	2.09	10.15	6.05	-100.00	14.61
		52	5.12	2.46	2.73	16.68	3.68	14.59	6.47	-100.00	17.76
I	36 MIL CSPE (S)	1	3.20	2.22	2.72	20.26	2.75	2.63	9.07	45.82	17.20
		2	3.90	2.53	2.90	20.02	2.67	2.50	10.09	117.47	19.86
		3	4.42	2.55	3.28	18.99	3.03	2.50	10.31	88.85	19.85
		4	4.87	2.58	3.34	19.00	2.99	2.64	10.72	24.76	20.35
		8	6.23	2.63	3.49	18.46	4.19	3.54	11.18	-100.00	22.19
		12	6.92	2.76	3.45	18.34	5.81	4.04	13.67	-100.00	16.67
		24	9.40	2.84	3.71	17.46	10.40	6.26	13.30	-100.00	17.91
		52	11.72	2.96	4.15	19.03	20.15	11.94	14.82	-100.00	22.01
J	38 MIL EIA (S)	1	2.10	0.72	1.54	52.12	0.53	1.99	11.14	-14.60	32.60
		2	2.58	0.93	1.85	44.41	0.19	2.03	10.94	-100.00	34.31
		3	2.73	1.06	1.93	42.41	-0.17	1.99	10.23	-100.00	31.97
		4	2.87	1.20	2.03	41.71	0.11	1.85	9.45	-100.00	33.14
		8	3.26	1.47	1.98	-100.00	0.54	1.42	7.57	-100.00	38.85
		12	3.26	1.71	2.08	-100.00	1.15	-0.12	8.88	-100.00	25.08
		24	3.89	1.77	2.39	-100.00	2.74	-2.72	6.41	-100.00	28.94
		52	4.03	1.81	2.38	-100.00	7.12	-5.22	5.77	-100.00	32.30

TABLE 17. PERCENT CHANGE IN WEIGHT AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
K	30 MIL EPDM (S)	1	1.83	1.97	1.88	5.01	1.80	2.39	4.59	-6.40	4.53
		2	2.26	2.01	1.91	4.97	2.84	1.85	3.98	-4.55	4.94
		3	2.45	2.00	2.01	4.59	1.75	1.52	4.23	-2.72	4.81
		4	2.42	2.00	1.99	4.66	1.41	1.43	4.02	-13.31	4.90
		8	2.76	1.62	1.82	5.45	0.98	1.80	3.74	-15.24	6.99
		12	2.64	1.61	1.77	5.80	1.18	1.57	4.53	4.99	6.40
		24	3.33	1.45	2.03	7.18	1.79	1.47	4.19	4.03	7.79
		52	3.55	1.55	2.94	8.61	3.76	1.29	4.74	4.03	11.80
L	30 MIL CPE (U)	1	1.24	0.99	0.93	44.89	0.50	-0.89	17.36	-100.00	45.02
		2	1.88	1.16	0.82	33.04	0.55	1.13	19.16	-100.00	58.13
		3	2.54	1.32	1.06	27.88	0.63	1.17	20.53	-100.00	68.26
		4	3.11	1.48	1.04	26.49	0.19	1.16	20.75	-100.00	77.33
		8	4.64	1.40	0.70	25.28	0.24	1.07	21.09	-100.00	108.98
		12	5.54	1.44	0.73	24.88	0.27	0.39	28.59	-100.00	60.56
		24	8.21	1.40	1.20	24.50	0.56	-0.78	28.56	-100.00	67.03
		52	10.19	1.41	1.10	25.61	1.41	-2.07	29.89	-100.00	67.60
M	30 MIL CPE (U)	1	1.41	0.58	1.83	43.86	0.50	1.07	22.28	-100.00	47.97
		2	2.10	0.80	1.66	33.81	0.72	1.07	23.96	-100.00	64.16
		3	2.81	0.97	1.84	27.72	0.41	1.20	26.24	-100.00	67.36
		4	3.42	1.12	1.71	26.61	0.41	1.21	26.69	-100.00	76.25
		8	4.94	1.25	1.61	25.46	0.57	1.20	27.23	-100.00	113.82
		12	5.93	1.30	1.69	25.43	0.59	0.64	35.94	-100.00	66.10
		24	8.31	1.30	1.98	25.00	0.80	-0.62	36.34	-100.00	74.76
		52	9.78	1.27	1.99	25.88	1.24	-2.22	38.63	-100.00	80.00
N	30 MIL HDPE (U)	1	0.01	0.02	0.09	-0.19	-0.44	-2.03	0.79	6.90	0.64
		2	0.02	0.00	0.04	-0.14	-0.30	-0.67	0.69	6.15	0.67
		3	0.03	0.01	0.08	-0.41	0.14	0.04	0.65	6.74	0.67
		4	0.01	0.05	0.11	-0.55	-0.86	0.02	0.55	5.51	0.71
		8	0.01	0.00	-0.02	-0.55	-0.79	0.23	0.35	6.06	0.69
		12	0.02	0.10	0.05	-0.49	-0.83	0.07	0.55	7.31	0.76
		24	0.01	-0.05	0.07	-0.49	-0.83	0.11	0.40	6.92	0.83
		52	-0.01	-0.01	0.14	-0.48	-0.28	0.32	0.39	6.74	0.83
0	80 MIL HDPE (U)	1	0.03	0.06	0.11	0.05	-0.29	-0.06	0.64	7.49	0.31
		2	0.04	0.06	0.09	0.03	0.09	0.05	0.76	7.22	0.24
		3	0.05	0.06	0.13	-0.08	-0.13	0.04	0.78	7.23	0.44
		4	0.05	0.08	0.12	-0.12	-0.31	0.03	0.76	6.03	0.49
		8	0.05	0.04	0.04	-0.10	-0.27	0.09	0.64	4.97	0.45
		12	0.05	0.10	0.08	-0.06	-0.26	0.07	0.89	7.54	0.00
		24	0.06	0.03	0.12	0.02	-0.16	0.12	0.65	7.36	0.67
		52	0.05	0.06	0.13	0.12	-0.29	0.19	0.55	4.07	0.59

TABLE 17. PERCENT CHANGE IN WEIGHT AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
P	80 MIL HDPE (U)	1	0.00	0.05	0.01	0.52	0.08	0.10	0.28	6.86	0.19
		2	0.01	0.03	0.07	0.34	-0.23	0.00	0.37	6.79	0.24
		3	0.00	0.05	0.08	-0.02	-0.26	-0.03	0.40	6.44	0.27
		4	0.01	0.08	0.11	-0.10	-0.34	0.01	0.39	5.33	0.25
		8	0.01	0.01	0.02	-0.08	-0.31	0.07	0.31	5.13	0.27
		12	0.01	0.07	0.10	-0.13	-0.32	0.04	0.43	6.83	0.33
		24	0.03	-0.01	--	-0.11	-0.32	0.04	0.23	6.79	0.34
		52	0.01	0.01	--	-0.01	-0.31	0.12	0.18	3.17	0.34
Q	80 MIL HDPE (U)	1	0.02	0.02	-0.03	0.04	-0.12	-0.36	0.40	7.67	0.07
		2	0.01	0.01	-0.02	0.18	0.03	-0.06	0.32	7.28	0.01
		3	0.00	0.04	0.00	-0.11	-0.23	-0.28	0.53	7.71	-0.04
		4	0.02	0.05	-0.01	-0.08	-0.32	0.03	0.49	6.45	0.43
		8	0.04	0.01	-0.05	0.03	-0.29	0.07	0.38	7.03	0.47
		12	0.04	0.05	-0.03	0.07	-0.23	0.09	0.59	7.85	0.49
		24	0.04	0.00	-0.02	0.17	-0.29	0.08	0.34	7.50	0.56
		52	0.06	0.02	0.00	-0.41	-0.26	0.14	0.28	4.78	0.51
R	30 MIL LLDPE (U)	1	0.05	0.08	0.02	0.03	-2.29	0.18	-0.44	4.38	0.51
		2	-0.03	0.04	0.00	-0.48	-0.13	-0.76	0.45	7.79	-0.57
		3	-0.02	0.04	0.00	-0.50	-0.30	0.05	0.60	7.76	0.57
		4	-0.02	0.09	0.01	-0.56	-0.92	0.05	0.55	5.11	0.56
		8	-0.01	0.08	-0.04	-0.56	-0.82	0.15	0.34	6.82	0.56
		12	-0.01	0.16	0.01	-0.56	-0.49	0.25	0.69	8.42	0.64
		24	-0.04	0.00	0.20	-0.53	-0.77	0.12	0.57	7.42	0.67
		52	0.00	0.07	0.27	-0.50	-0.79	0.21	0.63	7.52	0.72
S	30 MIL PVC (U)	1	0.50	-0.51	-0.08	-8.60	0.34	-0.98	14.95	-100.00	55.61
		2	0.59	-0.62	-0.30	-11.17	0.69	-1.19	12.15	-100.00	50.89
		3	0.68	-0.61	-0.28	-13.07	0.25	-1.02	12.26	-100.00	45.71
		4	0.83	-0.64	-0.23	-13.67	0.52	-1.15	10.94	-100.00	48.30
		8	1.09	-0.78	-0.41	-15.12	0.78	-1.07	8.06	-100.00	25.96
		12	1.08	-0.70	-0.55	-15.41	1.53	-1.68	8.12	-100.00	-2.91
		24	1.45	-0.89	-0.58	-15.98	3.34	-2.37	4.34	-100.00	0.77
		52	1.57	-0.97	-0.54	-16.38	6.41	-18.11	2.91	-100.00	5.55
T	30 MIL PVC (U)	1	0.72	-0.58	-0.15	-6.86	0.38	-0.06	10.45	-100.00	56.80
		2	0.94	-0.65	-0.08	-9.68	0.53	-0.60	9.65	-100.00	53.32
		3	1.15	-0.59	-0.23	-11.63	-0.04	-0.71	8.90	-100.00	46.14
		4	1.31	-0.65	-0.29	-12.63	0.25	-0.77	7.74	-100.00	49.17
		8	1.65	-0.71	-0.44	-14.28	0.34	-1.14	4.95	-100.00	28.03
		12	1.62	-0.68	-0.46	-14.67	0.82	-1.61	10.59	-100.00	0.49
		24	2.16	-0.74	-0.58	-14.62	1.69	-4.95	6.79	-100.00	5.68
		52	2.42	-0.81	-0.57	-15.90	3.69	-19.65	5.51	-100.00	13.12

TABLE 17. PERCENT CHANGE IN WEIGHT AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
U	30 MIL PVC (U)	1	0.38	-0.13	-0.19	-2.85	0.69	-0.79	11.57	-100.00	51.18
		2	0.56	-0.17	-0.27	-5.87	0.37	-0.22	10.17	-100.00	50.93
		3	0.72	-0.16	-0.30	-7.83	0.37	-0.34	10.46	-100.00	42.02
		4	0.81	-0.18	-0.29	-8.85	0.56	-0.39	9.33	-100.00	43.83
		8	1.06	-0.19	-0.41	-10.61	1.07	-0.36	6.58	-100.00	27.56
		12	1.13	-0.14	-0.40	-11.20	1.76	-0.71	8.66	-100.00	5.37
		24	1.45	-0.19	-0.50	-12.30	3.60	-1.94	4.84	-100.00	10.36
		52	1.53	-0.18	-0.50	-12.78	7.04	-14.97	11.37	-100.00	15.35

TABLE 18. PERCENT CHANGE IN THICKNESS AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
A	36 MIL	1	2.62	1.75	0.89	30.30	3.13	0.00	12.12	-100.00	21.21
	CPE (S)	2	3.79	2.63	1.78	30.30	3.13	3.03	15.15	-100.00	27.27
		3	4.37	3.22	2.66	221.21	18.75	18.18	33.33	-100.00	51.52
		4	4.66	3.51	2.66	169.70	-3.13	9.09	30.30	-100.00	51.52
		8	7.87	1.46	1.18	106.06	18.75	9.09	33.33	-100.00	54.55
		12	8.75	1.46	1.18	148.48	15.63	18.18	33.33	-100.00	42.42
		24	12.83	1.75	0.00	112.12	12.50	21.21	30.30	-100.00	57.58
		52	16.91	2.05	-0.30	87.88	25.00	9.09	39.39	-100.00	63.64
B	36 MIL	1	1.39	1.65	0.54	22.22	0.00	2.86	10.81	-100.00	25.00
	CPE(S)	2	2.50	1.37	0.54	22.22	0.00	2.86	13.51	-100.00	27.78
		3	3.06	1.37	1.08	25.00	5.41	20.00	21.62	-100.00	33.33
		4	3.61	1.65	0.27	25.00	2.70	17.14	10.81	-100.00	33.33
		8	5.00	0.55	-0.81	27.78	2.70	22.86	16.22	-100.00	36.11
		12	5.83	0.27	-1.35	33.33	5.41	25.71	10.81	-100.00	22.22
		24	7.22	0.27	-1.08	27.78	10.81	17.14	16.22	-100.00	25.00
		52	7.78	0.55	-1.89	22.22	18.92	11.43	5.41	-100.00	22.22
C	30 MIL	1	0.62	2.22	0.93	9.38	0.00	0.00	13.33	-100.00	3.03
	CSPE (S)	2	2.17	2.53	0.93	9.38	0.00	0.00	13.33	-100.00	3.03
		3	2.48	2.53	1.25	12.50	13.33	-3.03	26.67	-100.00	0.00
		4	3.11	2.85	1.25	12.50	10.00	6.06	20.00	-100.00	6.06
		8	1.86	1.90	1.56	9.38	6.67	6.06	20.00	-100.00	12.12
		12	2.48	1.90	1.25	18.75	3.33	9.09	16.67	-100.00	9.09
		24	2.80	1.90	2.18	12.50	0.00	6.06	23.33	-100.00	15.15
		52	3.73	2.85	2.18	12.50	-3.33	-3.03	13.33	-100.00	3.03
D	36 MIL	1	0.77	0.00	1.79	10.53	2.70	0.00	2.63	-100.00	5.26
	CSPE (S)	2	2.56	0.77	1.54	15.79	0.00	0.00	2.63	-100.00	7.89
		3	3.32	1.02	2.31	34.21	13.51	10.81	15.79	-100.00	39.47
		4	4.09	1.53	2.82	26.32	10.81	10.81	18.42	-100.00	34.21
		8	3.07	-0.51	0.26	28.95	10.81	10.81	21.05	-100.00	26.32
		12	3.58	-1.02	-0.26	28.95	10.81	13.51	36.84	-100.00	31.58
		24	4.86	0.51	0.00	23.68	8.11	16.22	34.21	-100.00	39.47
		52	7.93	0.00	0.26	23.68	5.41	0.00	47.37	-100.00	28.95
E	36 MIL	1	1.05	2.36	0.26	8.11	0.00	-2.70	8.33	-100.00	8.11
	CSPE (S)	2	1.84	1.84	0.51	18.92	0.00	-2.70	8.33	-100.00	8.11
		3	2.11	1.84	1.03	35.14	5.56	8.11	16.67	-100.00	24.32
		4	2.37	2.36	1.29	35.14	8.33	10.81	19.44	-100.00	21.62
		8	1.32	-1.05	-0.26	35.14	5.56	16.22	19.44	-100.00	24.32
		12	0.00	1.05	0.00	43.24	8.33	24.32	16.67	-100.00	21.62
		24	2.63	0.26	-1.03	35.14	5.56	5.41	16.67	-100.00	24.32
		52	2.37	2.10	-1.03	32.43	5.56	-5.41	16.67	-100.00	29.73

TABLE 18. PERCENT CHANGE IN THICKNESS AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
F	36 MIL CSPE (S)	1	0.44	-0.22	-1.98	4.55	0.00	0.00	-2.33	-100.00	0.00
		2	0.44	0.44	-0.88	11.36	0.00	-4.65	-2.33	-100.00	0.00
		3	0.87	1.10	-0.44	29.55	11.63	6.98	13.95	-100.00	13.64
		4	1.53	1.10	-0.44	36.36	4.65	6.98	9.30	-100.00	11.36
		8	-0.44	5.30	-1.10	45.45	11.63	6.98	11.63	-100.00	15.91
		12	-0.22	-0.22	-1.32	47.73	11.63	11.63	6.98	-100.00	20.45
		24	-0.44	-0.88	-3.08	50.00	9.30	4.65	6.98	-100.00	31.82
		52	0.65	4.42	-1.98	72.73	16.28	0.00	4.65	-100.00	34.09
G	36 MIL CSPE (S)	1	1.09	0.81	-0.27	13.89	0.00	0.00	2.86	-100.00	8.57
		2	1.63	1.34	0.00	16.67	0.00	-2.86	2.86	-100.00	8.57
		3	1.90	2.15	0.81	27.78	2.86	14.29	11.43	-100.00	28.57
		4	2.45	2.42	0.81	36.11	2.86	8.57	5.71	-100.00	22.86
		8	1.90	-0.27	-0.54	41.67	8.57	11.43	11.43	-100.00	31.43
		12	1.90	-0.27	-1.63	41.67	8.57	22.86	5.71	-100.00	20.00
		24	2.72	0.27	-1.08	25.00	2.86	8.57	14.29	-100.00	22.86
		52	5.16	-0.27	0.00	33.33	2.86	25.71	5.71	-100.00	17.14
H	36 MIL CSPE (S)	1	0.00	0.27	0.54	14.29	-2.78	-2.78	-2.78	-100.00	5.71
		2	0.54	0.81	0.54	14.29	-2.78	-5.56	0.00	-100.00	5.71
		3	0.81	1.36	1.08	25.71	5.56	8.33	11.11	-100.00	20.00
		4	1.62	1.63	1.35	31.43	2.78	2.78	2.78	-100.00	17.14
		8	0.27	0.27	-0.27	40.00	0.00	13.89	0.00	-100.00	25.71
		12	0.81	0.27	-0.81	42.86	8.33	16.67	0.00	-100.00	17.14
		24	0.54	-0.27	-1.08	25.71	0.00	11.11	2.78	-100.00	25.71
		52	0.54	-0.27	-0.81	40.00	2.78	0.00	2.78	-100.00	22.86
I	36 MIL CSPE (S)	1	0.54	1.37	0.27	25.71	2.86	-2.86	5.71	-100.00	14.29
		2	0.81	1.10	0.00	22.86	2.86	-2.86	5.71	-100.00	14.29
		3	1.35	1.10	0.27	37.14	11.43	14.29	14.29	-100.00	28.57
		4	1.35	1.64	0.54	34.29	5.71	5.71	11.43	-100.00	25.71
		8	2.16	-0.55	-1.08	40.00	8.57	17.14	22.86	-100.00	22.86
		12	2.16	-0.82	-1.90	42.86	11.43	31.43	11.43	-100.00	17.14
		24	3.78	0.00	-1.63	20.00	8.57	25.71	17.14	-100.00	11.43
		52	5.41	-0.55	-1.08	31.43	25.71	34.29	22.86	-100.00	22.86
J	38 MIL EIA (S)	1	0.89	0.88	1.18	85.29	0.00	0.00	8.82	-100.00	45.95
		2	0.89	1.47	1.48	52.94	0.00	0.00	11.76	-100.00	35.14
		3	1.49	1.76	1.78	61.76	2.94	-5.88	14.71	-100.00	40.54
		4	1.79	2.06	2.37	58.82	2.94	0.00	8.82	-100.00	43.24
		8	1.49	1.76	0.00	-100.00	-2.94	5.88	14.71	-100.00	35.14
		12	1.49	1.18	-0.59	-100.00	2.94	2.94	11.76	-100.00	24.32
		24	1.49	1.18	0.30	-100.00	2.94	0.00	5.88	-100.00	29.73
		52	1.49	0.59	-0.30	-100.00	11.76	0.00	20.59	-100.00	40.54

TABLE18. PERCENT CHANGE IN THICKNESS AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
K	30 MIL EPDM (S)	1	0.23	1.15	8.48	4.55	0.00	0.00	4.65	11.63	4.65
		2	0.46	0.69	8.73	6.82	0.00	0.00	4.65	6.98	4.65
		3	0.69	0.46	8.98	13.64	-2.27	2.33	11.63	23.26	9.30
		4	0.46	0.46	9.23	11.36	6.82	6.98	6.98	41.86	4.65
		8	0.46	-0.92	7.73	13.64	4.55	13.95	9.30	30.23	6.98
		12	0.93	-0.69	7.48	15.91	6.82	13.95	9.30	16.28	6.98
		24	0.46	-0.92	7.23	11.36	6.82	6.98	4.65	18.60	16.28
		52	0.69	-1.38	7.23	15.91	4.55	9.30	9.30	6.98	9.30
L	30 MIL CPE (U)	1	1.26	0.95	2.55	37.50	0.00	0.00	15.63	-100.00	28.13
		2	2.21	1.90	2.55	28.13	0.00	0.00	15.63	-100.00	37.50
		3	2.84	2.54	2.87	34.38	0.00	9.38	25.00	-100.00	53.13
		4	3.47	3.49	2.23	25.00	6.25	6.25	21.88	-100.00	59.38
		8	4.73	4.44	4.46	28.13	6.25	6.25	21.88	-100.00	71.88
		12	6.31	4.13	3.50	28.13	12.50	9.38	34.38	-100.00	40.63
		24	8.52	4.44	5.10	18.75	3.13	0.00	28.13	-100.00	50.00
		52	10.41	4.13	5.10	25.00	12.50	3.13	28.13	-100.00	37.50
M	30 MIL CPE (U)	1	0.63	1.59	4.79	37.50	0.00	3.33	30.00	-100.00	32.26
		2	1.58	1.91	4.47	31.25	0.00	3.33	23.33	-100.00	38.71
		3	1.90	2.87	5.11	28.13	9.38	10.00	40.00	-100.00	48.39
		4	2.53	4.14	4.47	28.13	6.25	13.33	23.33	-100.00	54.84
		8	4.43	2.23	8.95	34.38	9.38	13.33	26.67	-100.00	67.74
		12	5.38	1.91	7.67	28.13	3.13	10.00	46.67	-100.00	48.39
		24	8.23	1.91	9.27	25.00	3.13	-3.33	50.00	-100.00	58.06
		52	10.13	1.59	8.95	25.00	-3.13	0.00	46.67	-100.00	48.39
N	30 MIL HDPE (U)	1	1.30	0.63	3.50	0.00	0.00	6.67	3.45	0.00	-3.33
		2	0.98	0.94	3.18	0.00	3.33	0.00	3.45	3.45	0.00
		3	1.30	1.25	3.50	10.00	3.33	3.33	10.34	17.24	6.67
		4	0.98	1.56	3.50	10.00	10.00	13.33	10.34	24.14	13.33
		8	0.65	0.00	3.18	13.33	10.00	10.00	10.34	20.69	3.33
		12	0.98	0.94	2.23	0.00	13.33	6.67	6.90	13.79	3.33
		24	-0.65	1.25	2.55	3.33	3.33	3.33	13.79	44.83	20.00
		52	-0.33	-3.75	2.55	56.67	3.33	10.00	0.00	6.90	6.67
O	80 MIL HDPE (U)	1	0.00	0.75	0.13	17.72	0.00	-3.85	0.00	9.09	1.25
		2	0.00	0.38	0.13	1.27	-2.44	-1.28	-6.10	7.79	0.00
		3	0.00	0.63	0.40	2.53	-2.44	1.28	-2.44	12.99	2.50
		4	0.13	0.88	0.26	2.53	1.22	-1.28	-6.10	9.09	8.75
		8	-0.13	0.88	-0.79	2.53	0.00	3.85	-2.44	9.09	3.75
		12	0.13	-1.50	-0.66	-1.27	1.22	0.00	-4.88	9.09	0.00
		24	-0.65	-3.50	-0.66	16.46	1.22	-1.28	-2.44	7.79	16.25
		52	-0.39	-4.13	-0.53	17.72	0.00	-2.56	-4.88	9.09	21.25

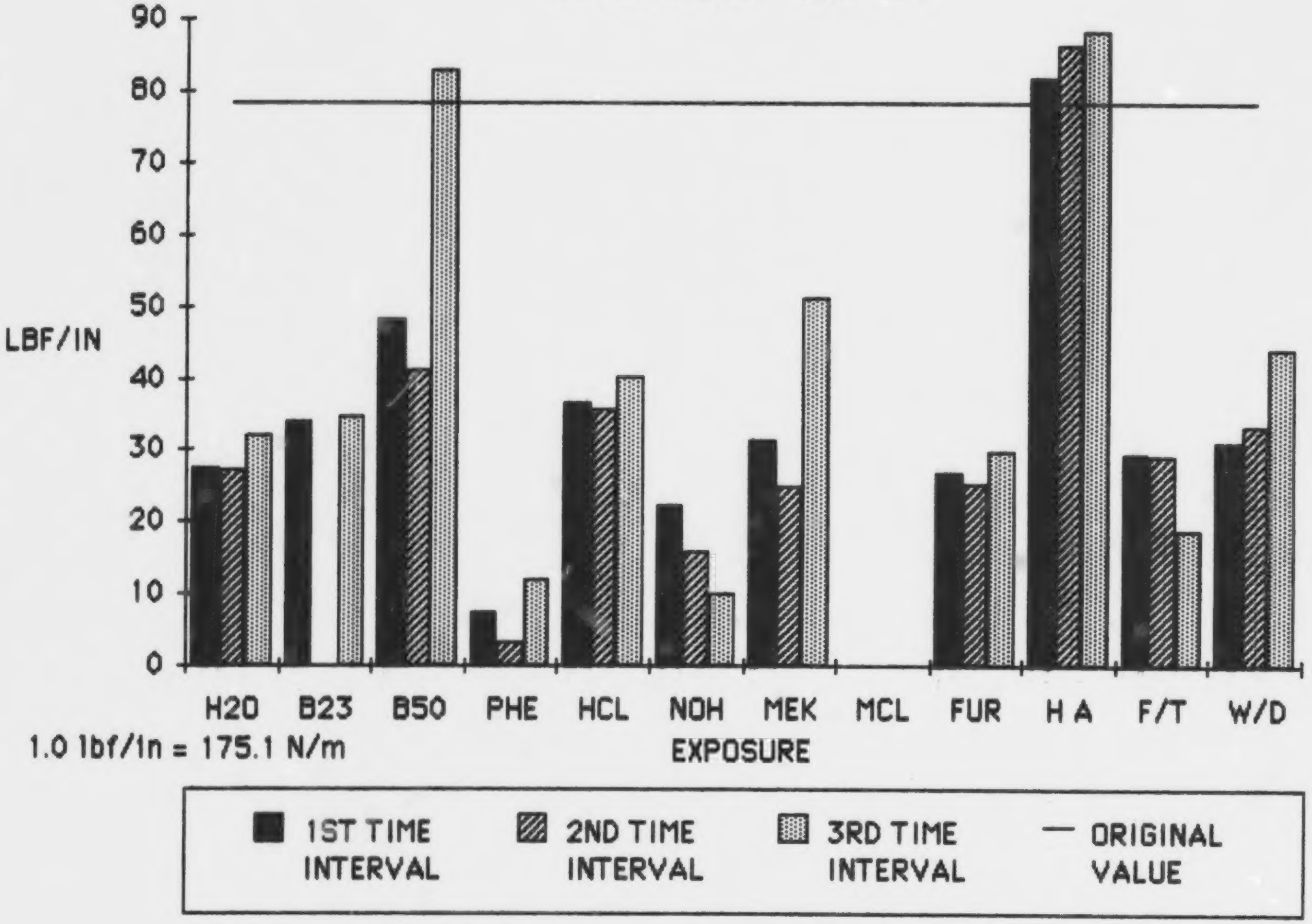
TABLE 18. PERCENT CHANGE IN THICKNESS AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
P	80 MIL HDPE (U)	1	0.26	0.13	0.13	3.53	-2.22	2.06	-7.45	10.34	1.01
		2	0.26	0.13	0.13	5.88	-2.22	3.09	-10.64	11.49	0.00
		3	0.13	0.39	0.13	5.88	1.11	7.22	-7.45	10.34	4.04
		4	0.13	0.51	0.38	7.06	0.00	6.19	-2.13	12.64	5.05
		8	-0.64	0.90	-0.88	8.24	-3.33	9.28	-5.32	14.94	5.05
		12	0.00	1.54	-0.50	7.06	2.22	7.22	-6.38	17.24	2.02
		24	-1.03	1.16	—	1.18	-2.22	6.16	-5.32	24.14	4.04
		52	-1.03	0.77	—	25.88	-4.44	6.19	-6.38	18.39	5.05
Q	80 MIL HDPE (U)	1	0.00	0.36	0.00	12.79	0.00	-1.16	4.88	-1.18	7.53
		2	0.00	0.12	0.24	0.00	1.23	-1.16	6.10	-2.35	2.15
		3	0.00	0.24	0.36	1.16	2.47	18.60	34.15	3.53	-5.38
		4	0.12	0.24	0.36	0.00	2.47	0.00	3.66	1.18	-6.45
		8	-0.47	-0.36	0.12	0.00	1.23	-2.33	4.88	8.24	-7.53
		12	-0.36	-0.12	0.00	1.16	2.47	22.09	6.10	-1.18	-10.75
		24	-0.36	-0.12	0.00	8.14	1.23	4.65	17.07	9.41	7.53
		52	-0.71	-0.24	0.00	16.28	3.70	1.16	24.39	-3.53	0.00
R	30 MIL LLDPE (U)	1	0.00	1.59	1.92	0.00	-3.13	9.09	0.00	0.00	3.13
		2	0.32	0.95	1.60	3.13	-3.13	9.09	0.00	0.00	3.13
		3	0.64	0.95	1.60	6.25	0.00	42.42	3.13	-3.03	6.25
		4	0.64	1.27	2.24	9.38	9.38	39.39	43.75	3.03	6.25
		8	0.00	-0.32	1.28	6.25	9.38	9.09	21.88	12.12	6.25
		12	-0.64	0.32	2.24	9.38	9.38	18.18	21.88	3.03	3.13
		24	0.00	-0.32	0.96	3.13	12.50	15.15	0.00	9.09	46.88
		52	-0.64	-0.32	1.28	9.38	3.13	27.27	-3.13	0.00	9.38
S	30 MIL PVC (U)	1	0.72	1.44	0.72	-3.57	0.00	0.00	11.11	-100.00	14.29
		2	1.08	0.72	0.00	-3.57	3.70	0.00	11.11	-100.00	14.29
		3	1.43	1.08	0.00	3.57	7.41	7.14	14.81	-100.00	25.00
		4	1.79	0.72	0.72	3.57	14.81	10.71	14.81	-100.00	21.43
		8	1.08	-0.36	1.44	7.14	11.11	3.57	7.41	-100.00	7.14
		12	0.72	-0.36	1.08	7.14	11.11	0.00	22.22	-100.00	-7.14
		24	1.08	0.00	1.80	0.00	3.70	0.00	22.22	-100.00	-3.57
		52	1.08	-0.36	1.44	-3.57	11.11	57.14	22.22	-100.00	-3.57
T	30 MIL PVC (U)	1	0.92	0.31	0.62	-3.13	0.00	0.00	9.38	-100.00	18.75
		2	0.92	0.00	0.62	-3.13	0.00	0.00	9.38	-100.00	15.63
		3	1.23	0.93	0.00	9.38	3.13	-3.13	9.38	-100.00	31.25
		4	1.54	0.93	-0.31	3.13	9.38	9.38	6.25	-100.00	28.13
		8	0.92	-0.93	0.62	3.13	9.38	3.13	15.63	-100.00	18.75
		12	0.92	-1.23	0.31	0.00	6.25	6.25	18.75	-100.00	0.00
		24	1.23	-0.62	0.92	-6.25	6.25	12.50	15.63	-100.00	6.25
		52	1.23	-0.93	0.92	6.25	3.13	12.50	18.75	-100.00	9.38

TABLE 18. PERCENT CHANGE IN THICKNESS AFTER EXPOSURE

	MATERIAL	WEEK	WATER PERCENT CHANGE	23° BRINE PERCENT CHANGE	50° BRINE PERCENT CHANGE	PHENOL PERCENT CHANGE	HCL PERCENT CHANGE	NAOH PERCENT CHANGE	MEK PERCENT CHANGE	MCL PERCENT CHANGE	FURFURAL PERCENT CHANGE
U	30 MIL	1	-0.33	0.67	0.33	10.00	0.00	-3.23	6.67	-100.00	16.67
	PVC (U)	2	0.33	0.67	0.66	0.00	0.00	-3.23	6.67	-100.00	16.67
		3	0.67	1.34	0.00	16.67	6.67	-3.23	3.33	-100.00	20.00
		4	1.00	0.67	0.33	16.67	6.67	3.23	16.67	-100.00	20.00
		8	0.33	0.67	0.66	33.33	6.67	3.23	-3.33	-100.00	20.00
		12	0.33	0.34	0.33	30.00	6.67	-3.23	10.00	-100.00	6.67
		24	0.33	0.67	1.00	26.67	3.33	0.00	6.67	-100.00	6.67
		52	0.33	0.34	1.00	30.00	3.33	22.58	0.00	-100.00	6.67

Figure 29. SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CPE (S) - SAMPLE 1



1.0 lbf/in = 175.1 N/m

Figure 30. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CPE (S) - SAMPLE 1

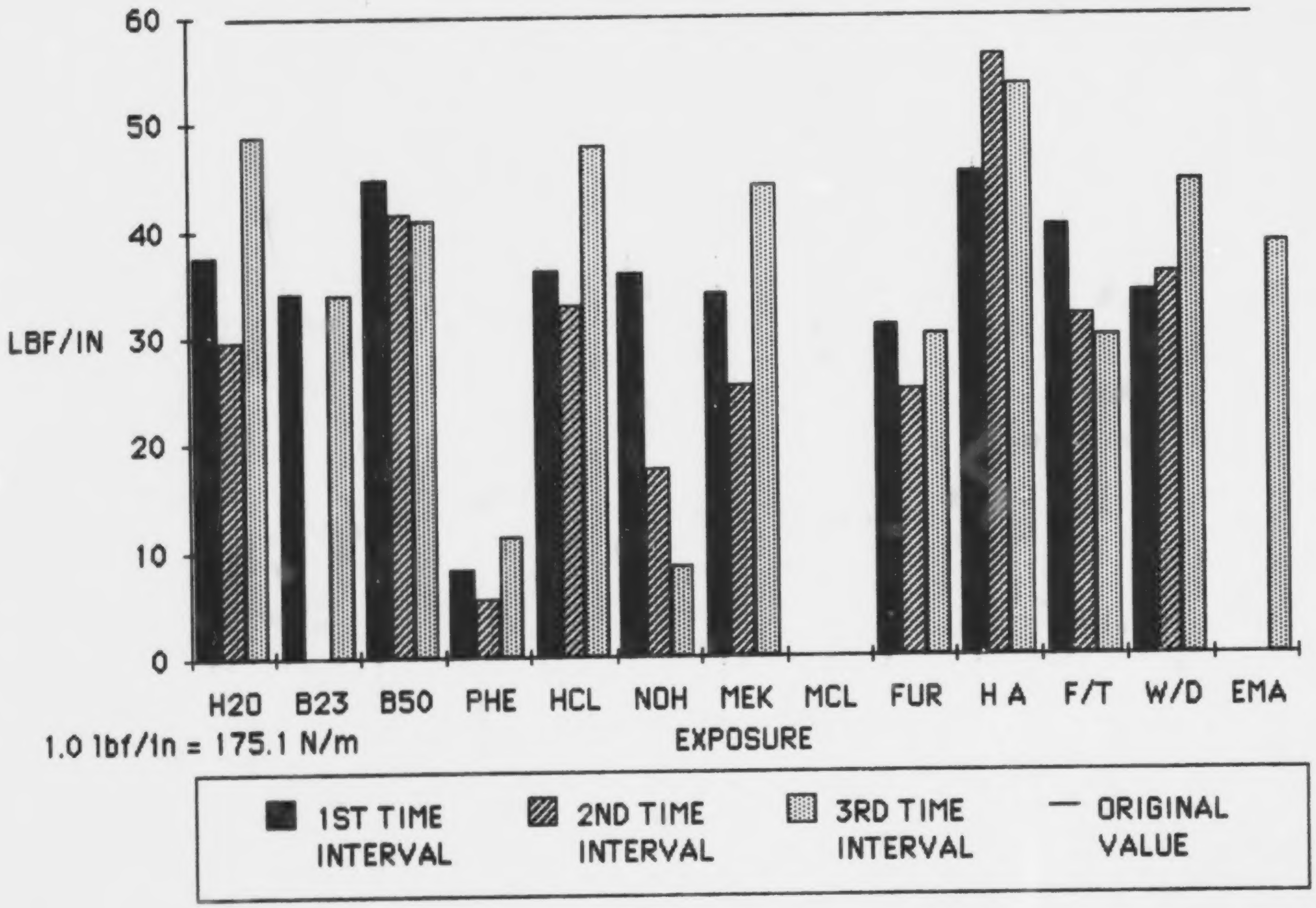
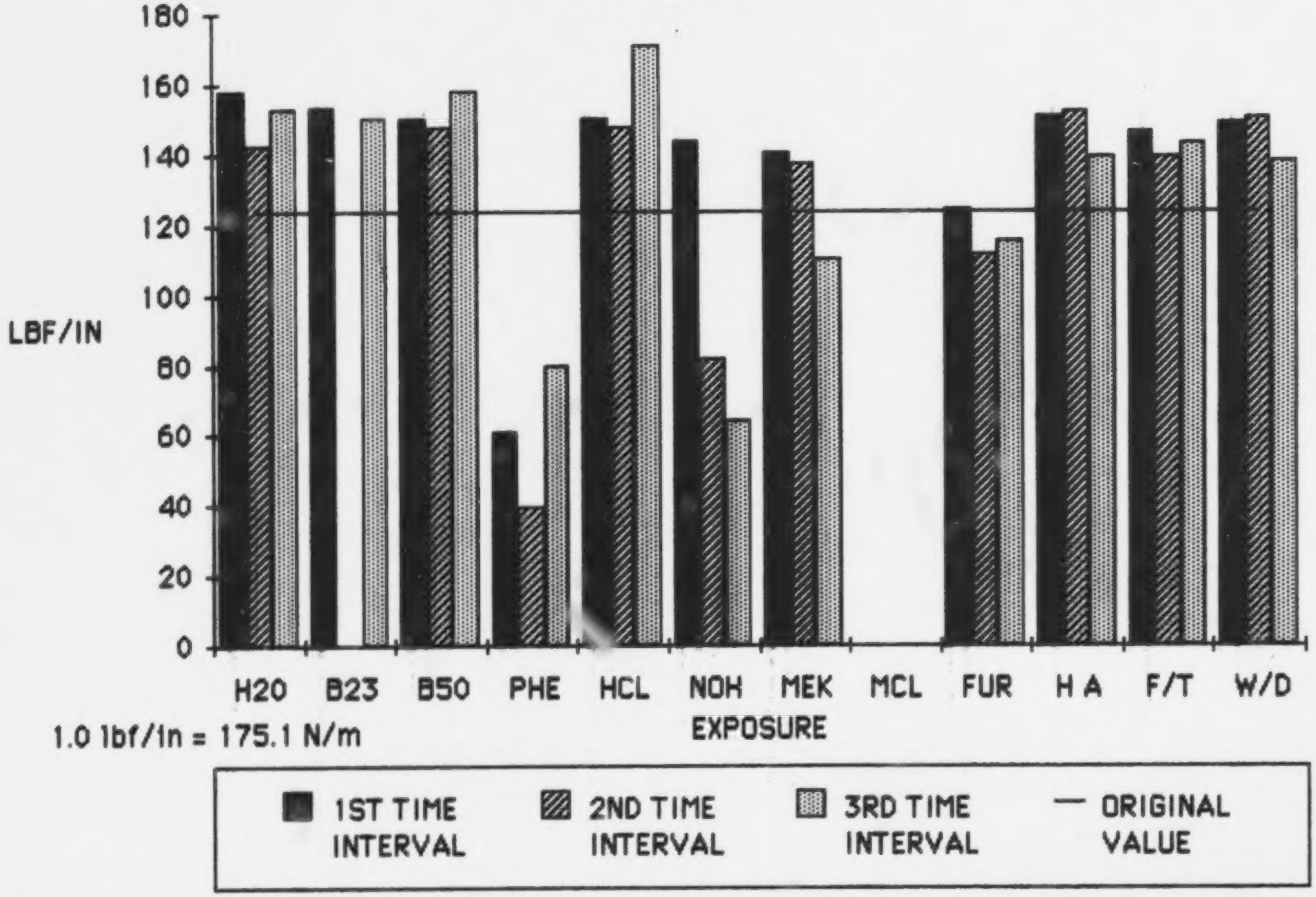
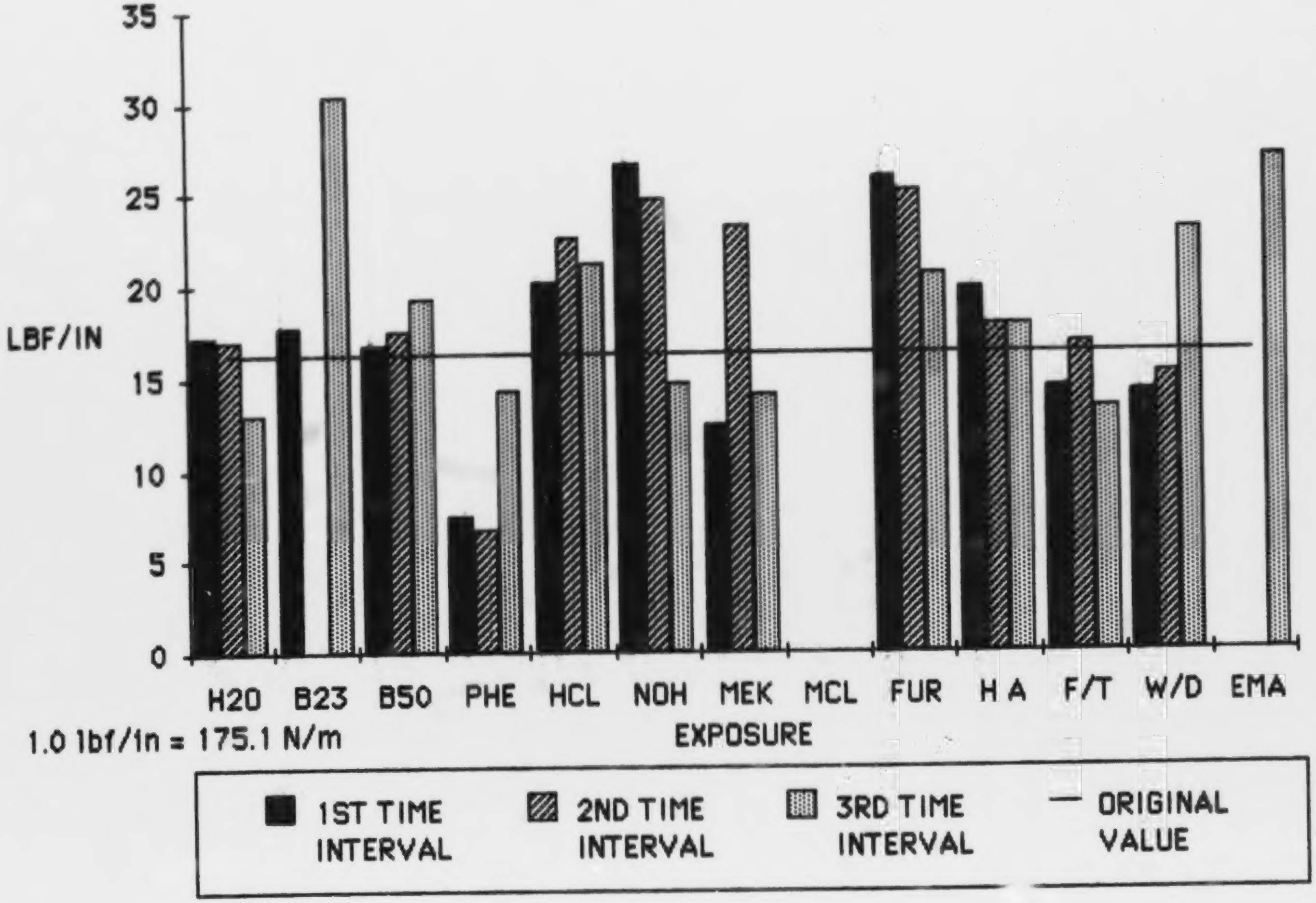


Figure 31. SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CPE (S) - SAMPLE 2



1.0 lbf/in = 175.1 N/m

Figure 32. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CPE (S) - SAMPLE 2



1.0 lbf/in = 175.1 N/m

Figure 33. SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 30 MIL CSPE (S) - SAMPLE 3

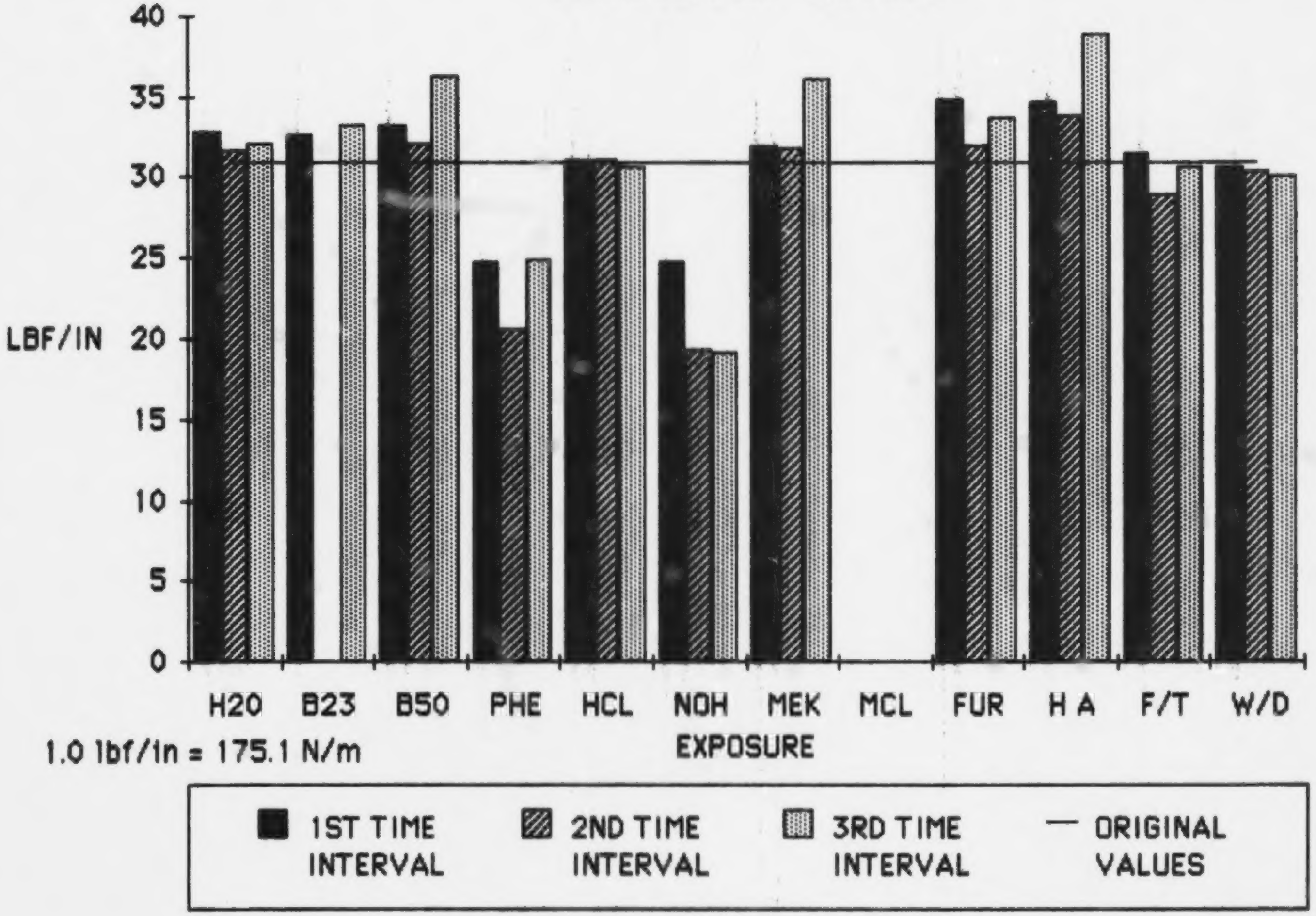


Figure 34. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 30 MIL CSPE (S) - SAMPLE 3

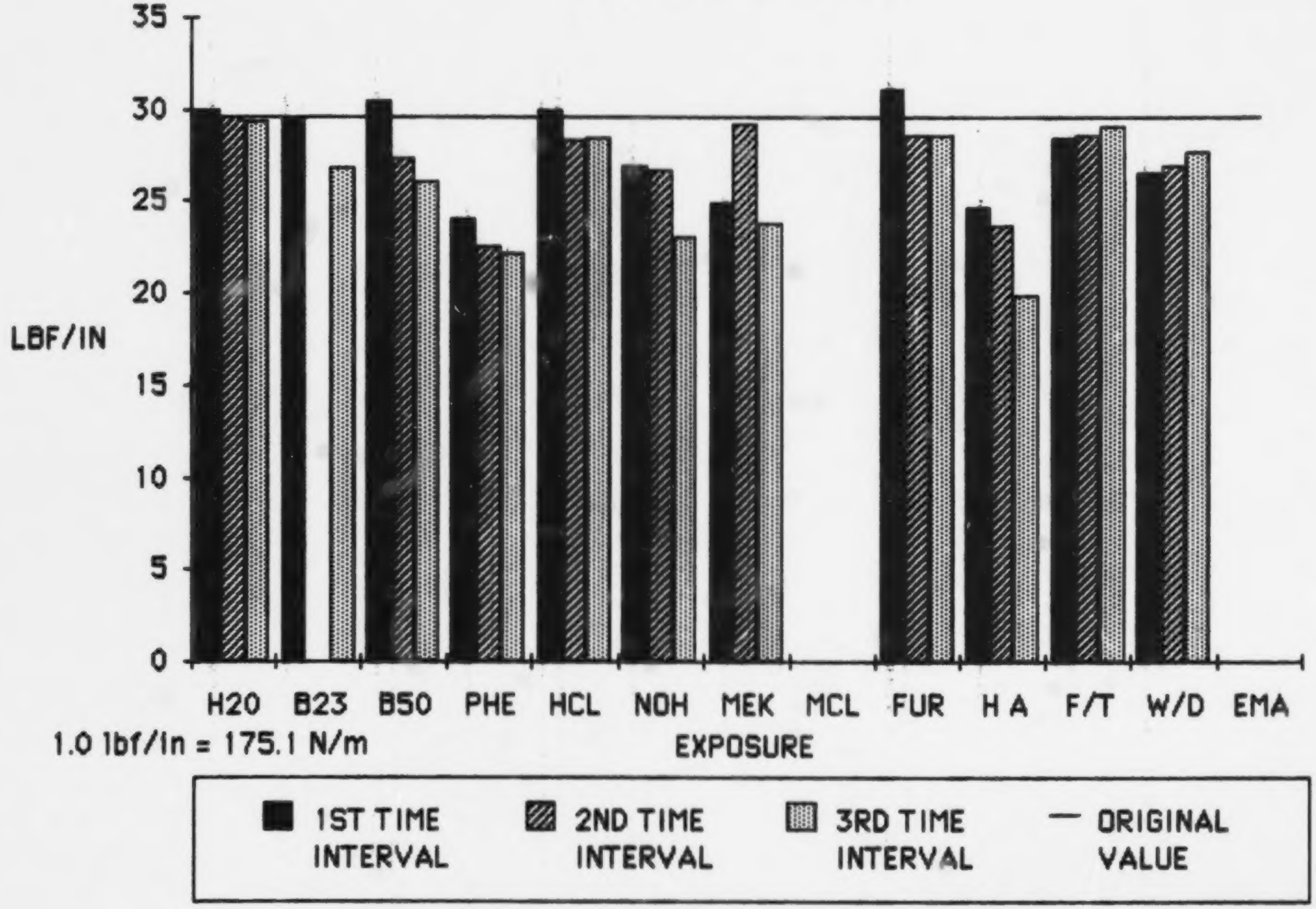


Figure 35. SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 4

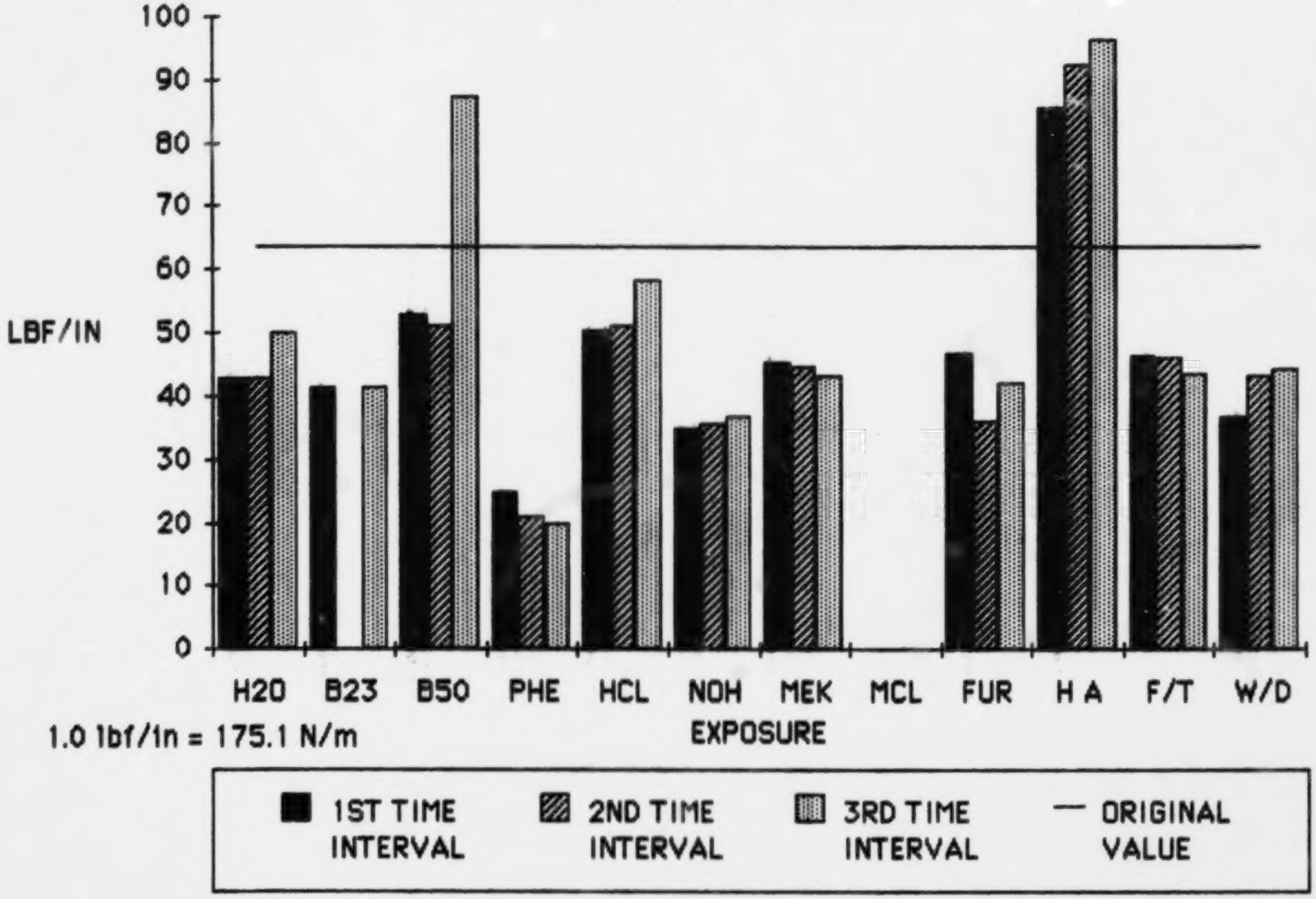


Figure 36. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 4

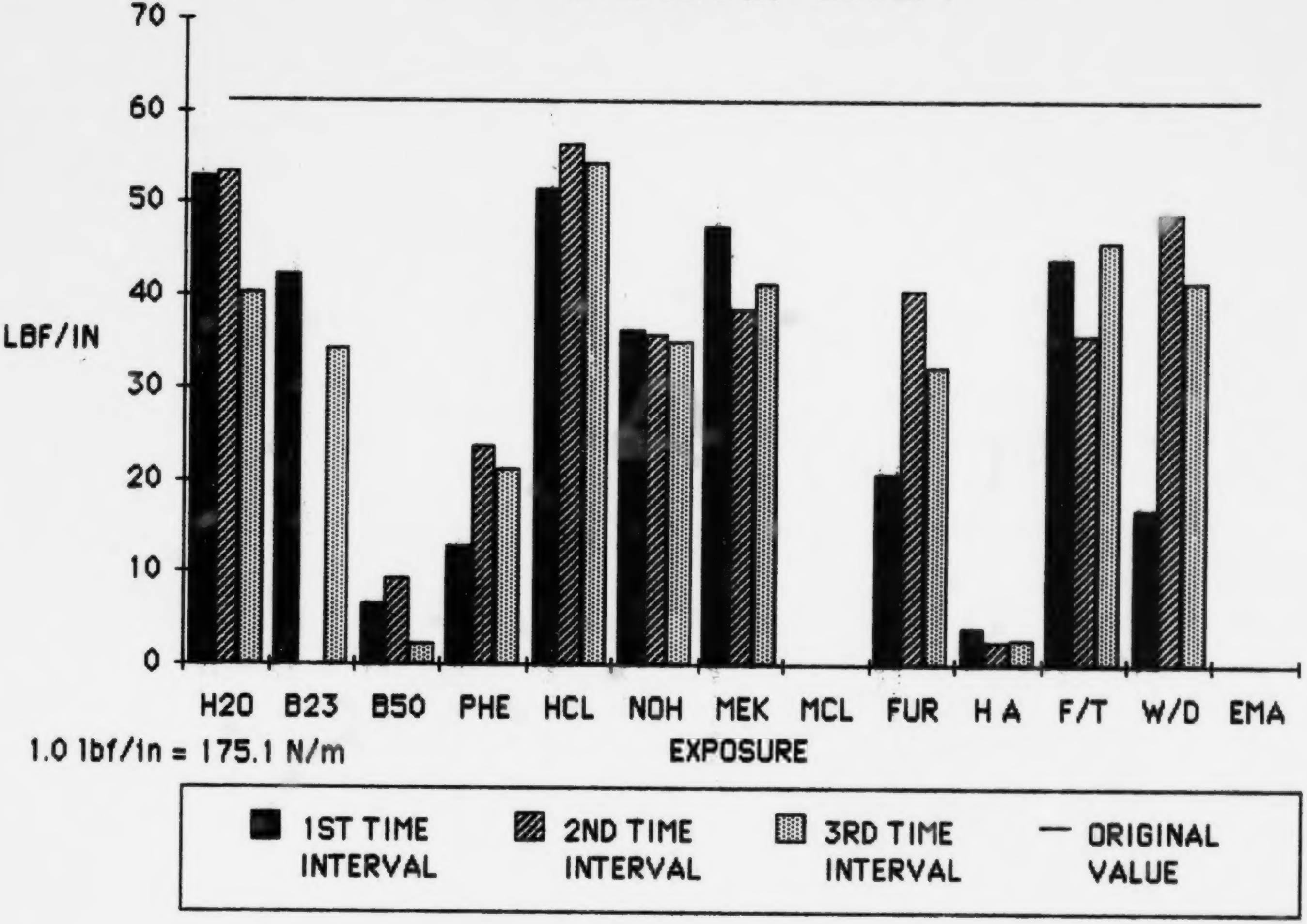


Figure 37. SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 5

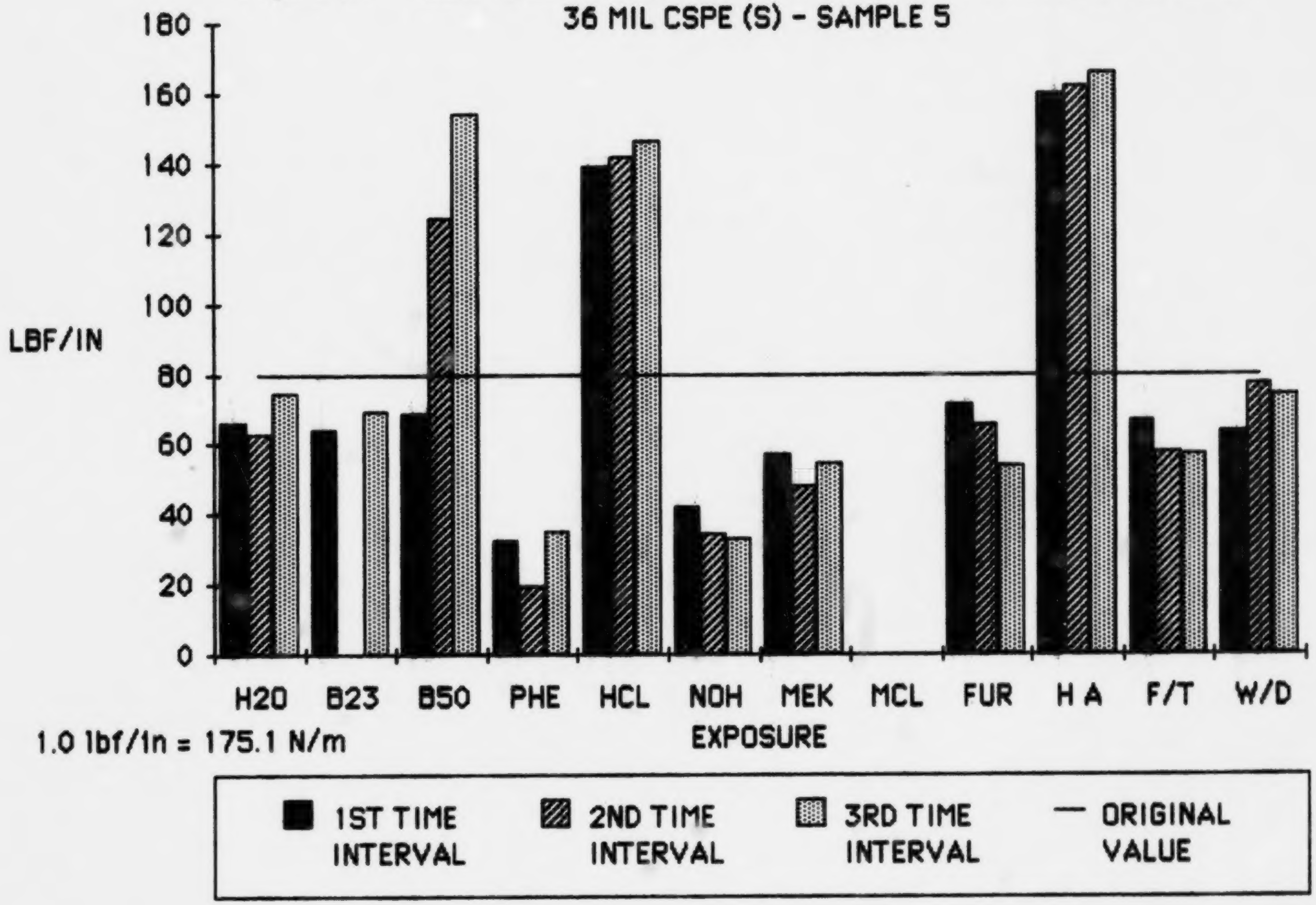
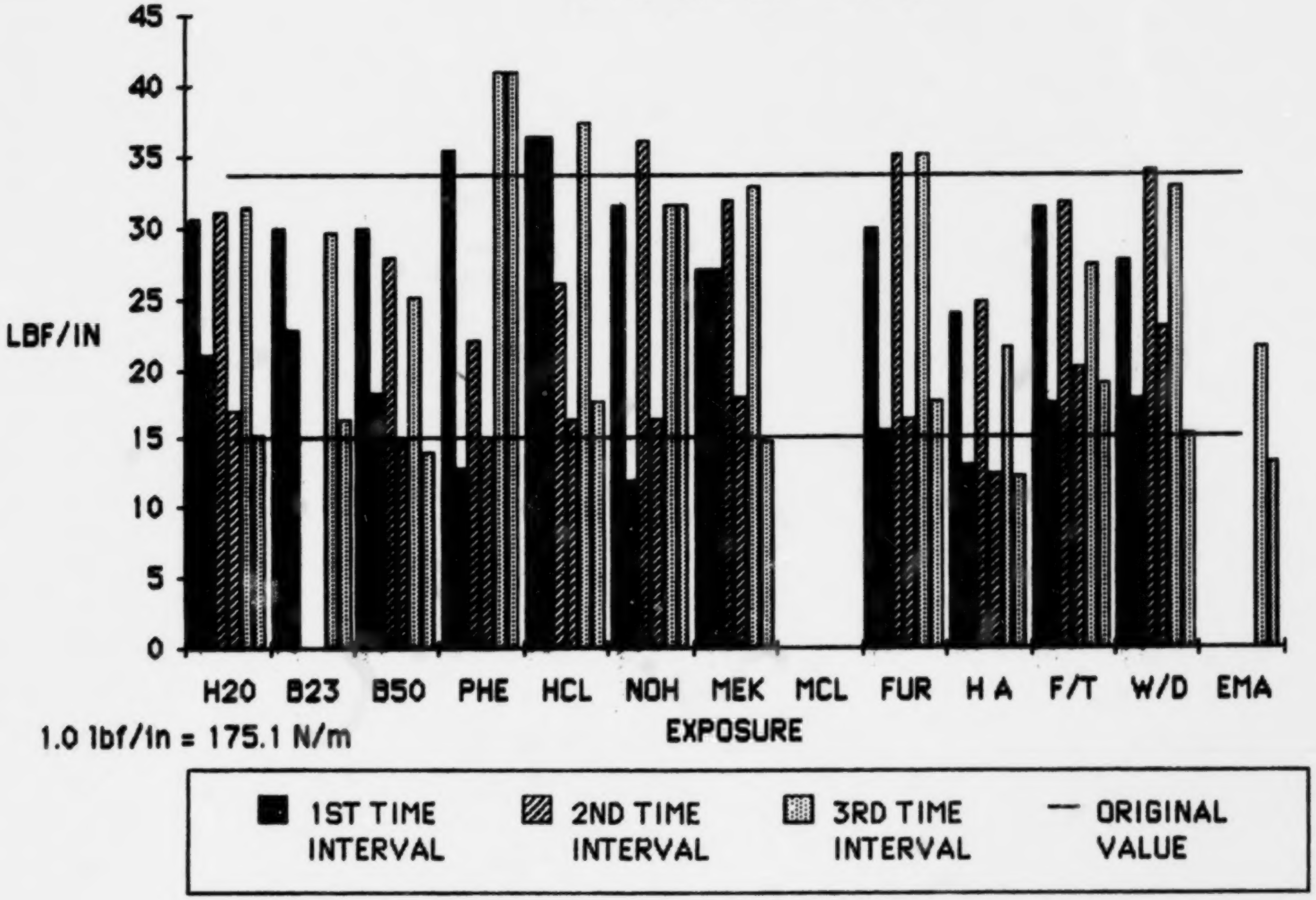
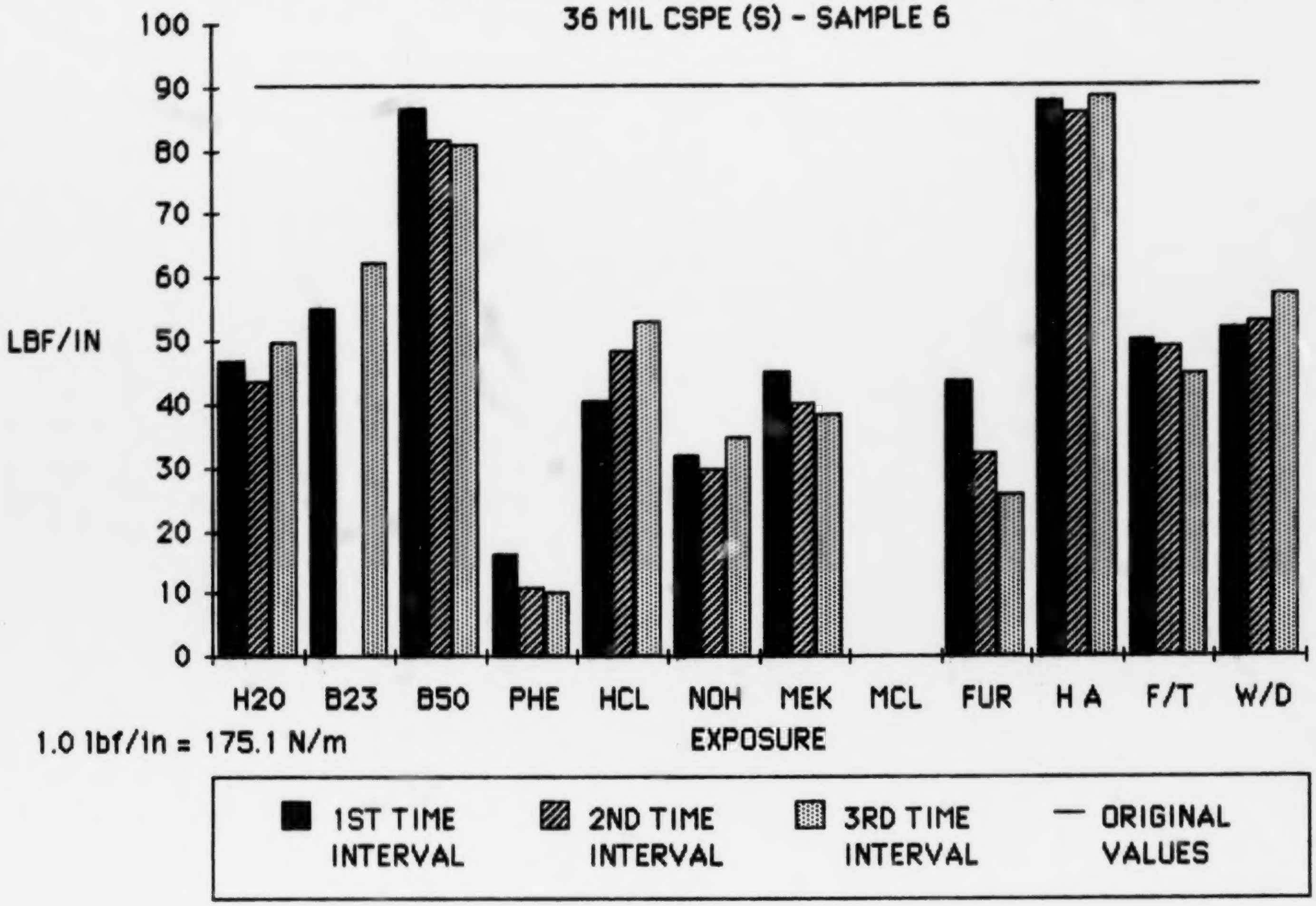


Figure 38. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 5



1.0 lbf/in = 175.1 N/m

Figure 39. SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 6



1.0 lbf/in = 175.1 N/m

Figure 40. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 6

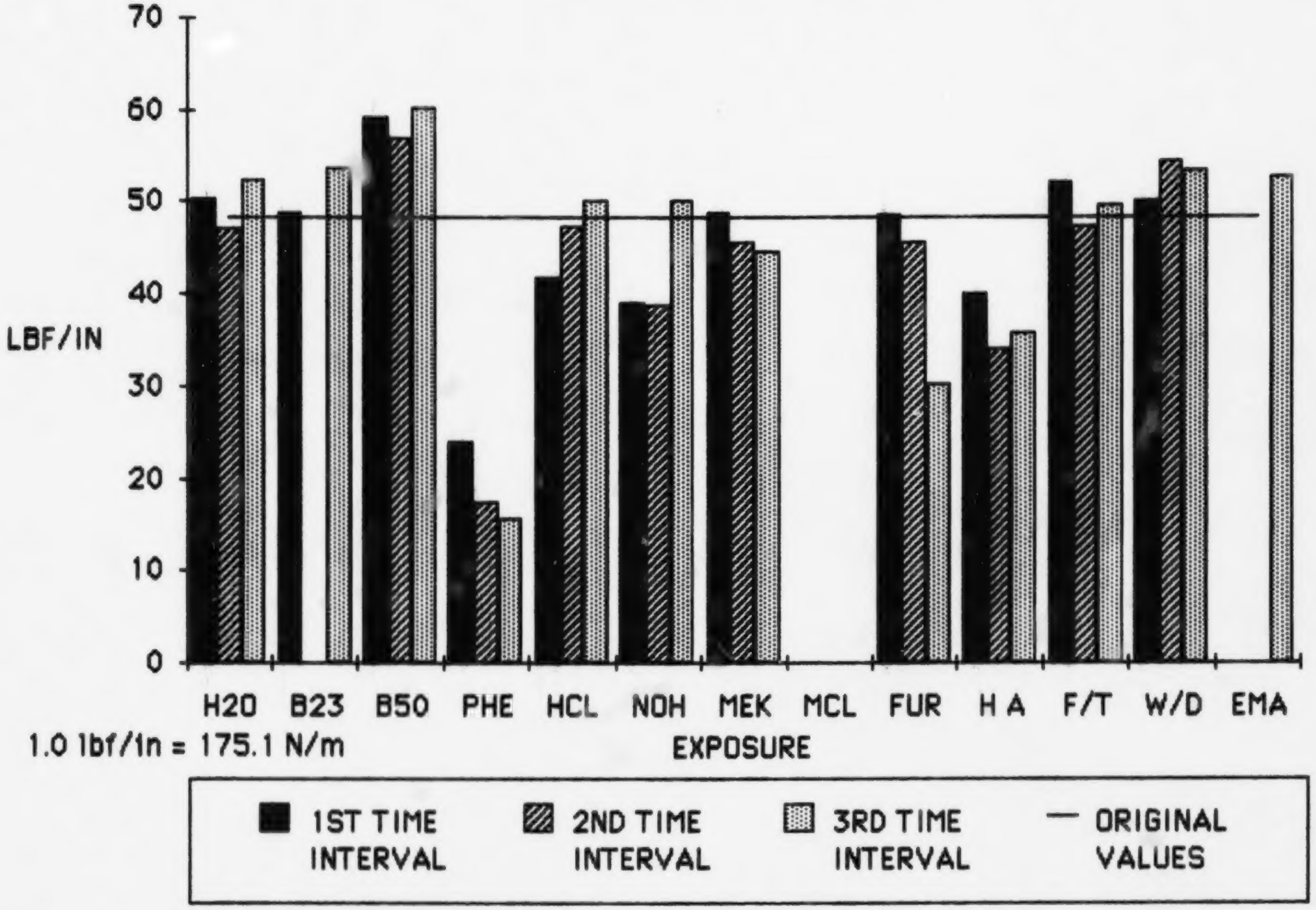


Figure 41. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 7

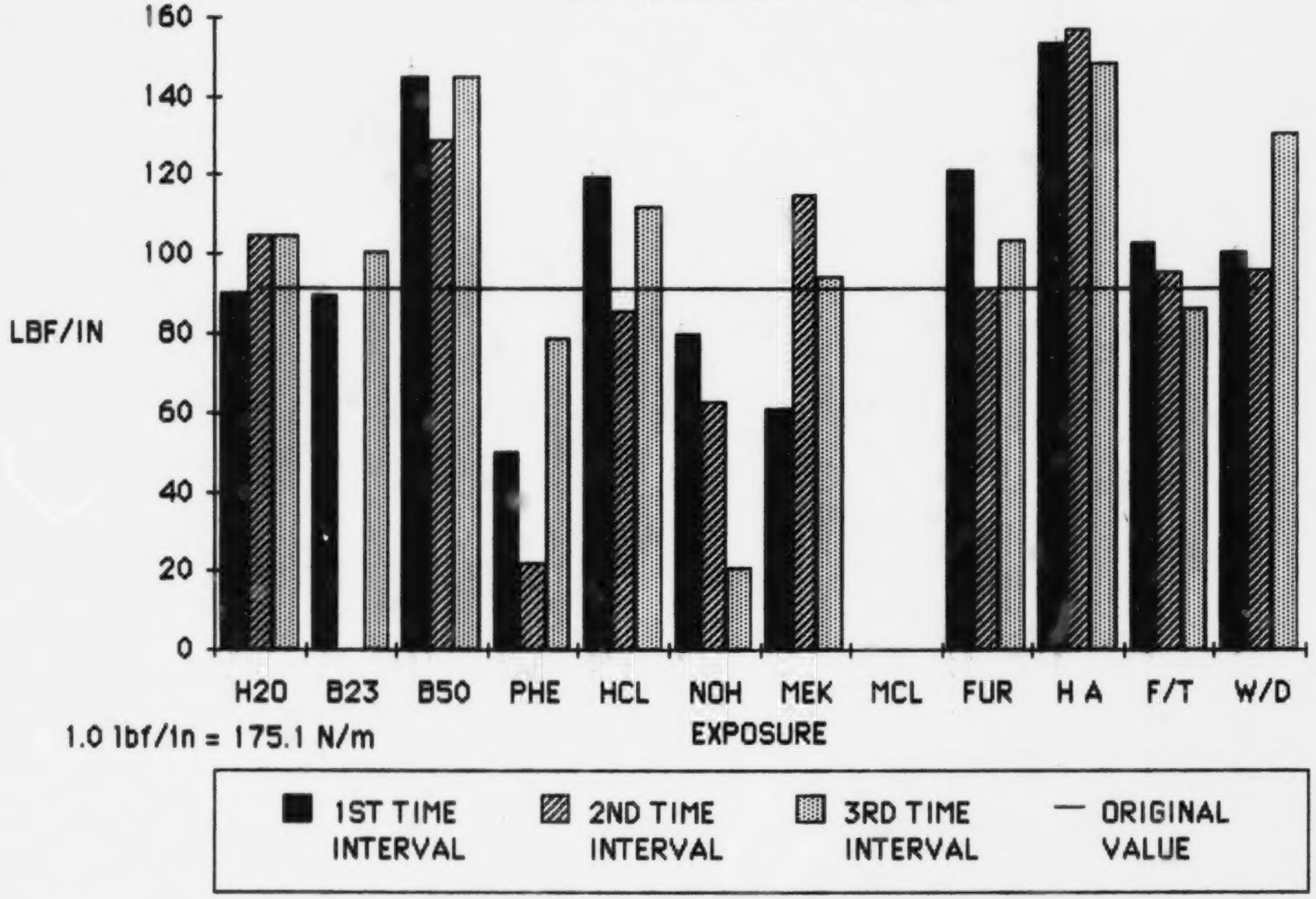


Figure 42. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 7

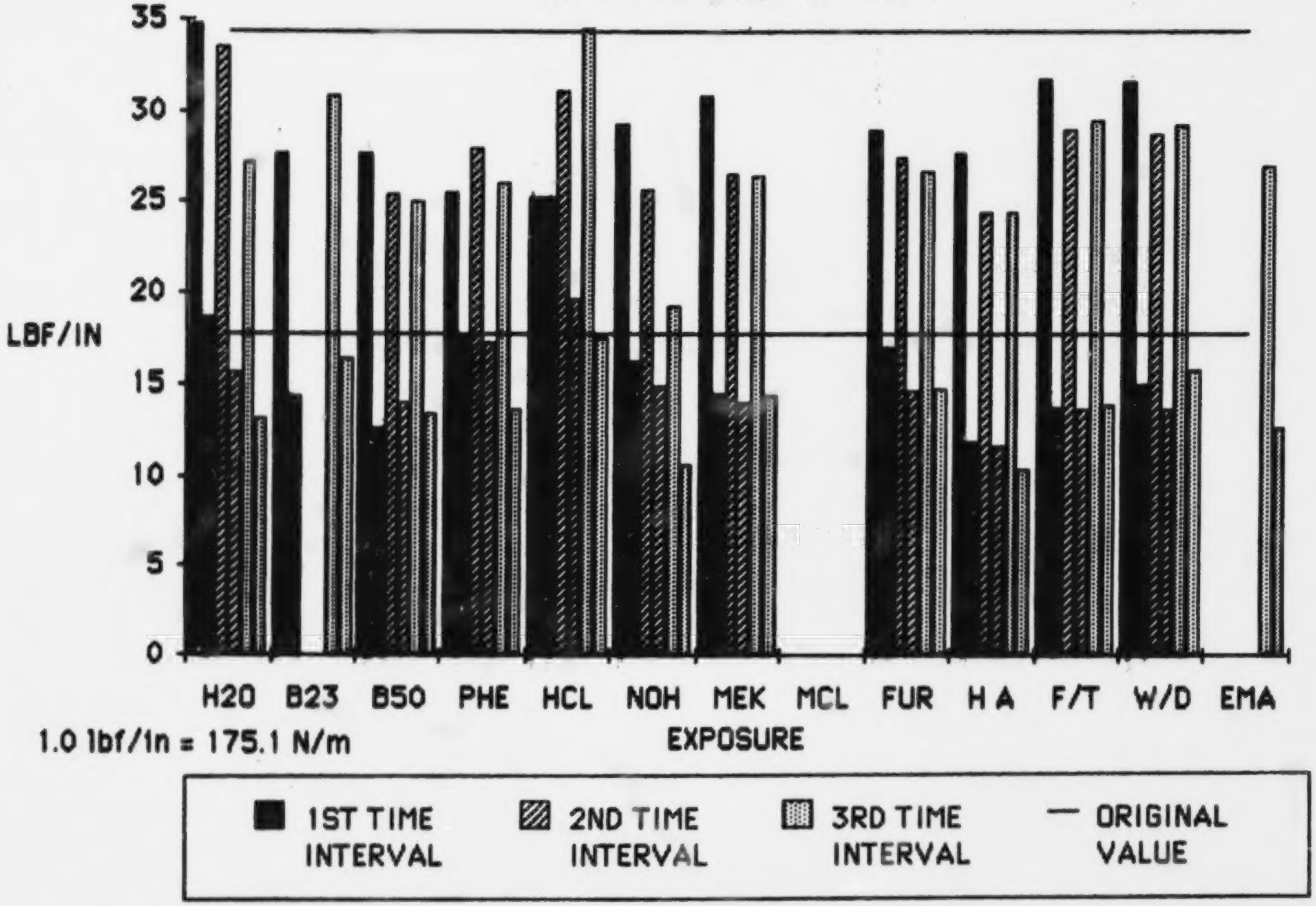
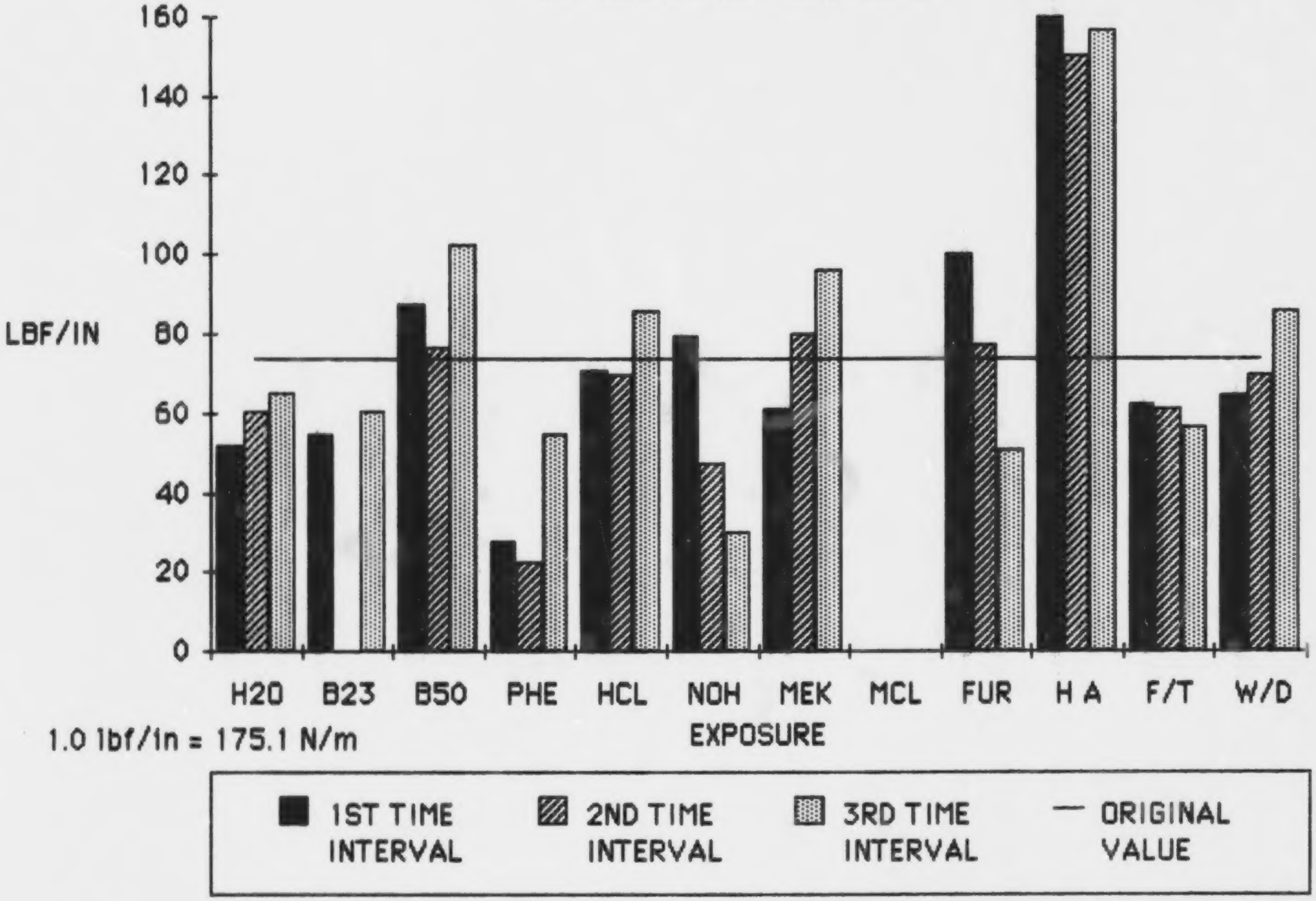


Figure 43. SEAM SHEAR STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 8



1.0 lbf/in = 175.1 N/m

Figure 44. SEAM PEEL STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 36 MIL CSPE (S) - SAMPLE 8

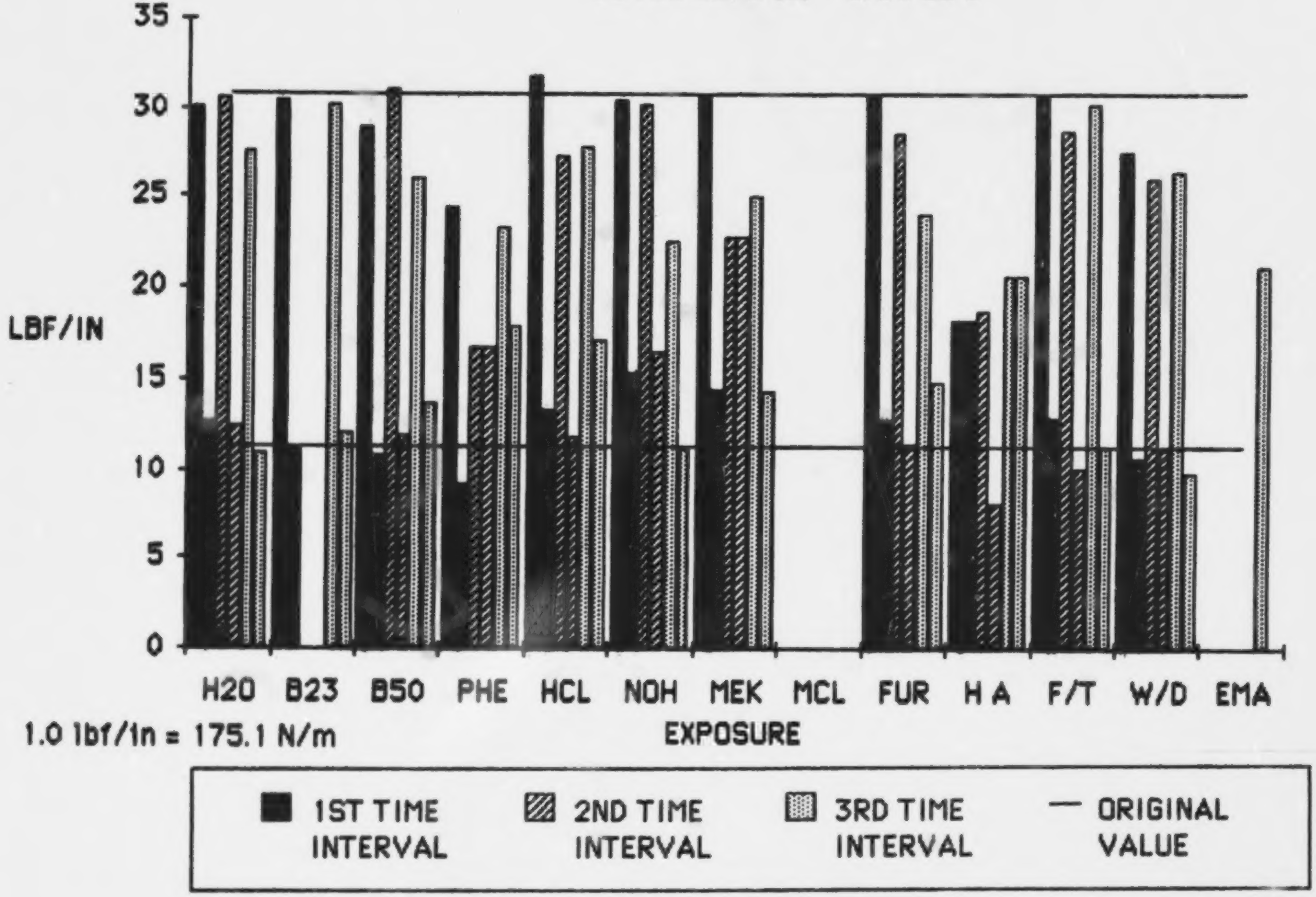


Figure 45. **SEAM SHEAR STRENGTH - THERMAL HOT AIR FACTORY SEAM - 38 MIL EIA (S) - SAMPLE 9**

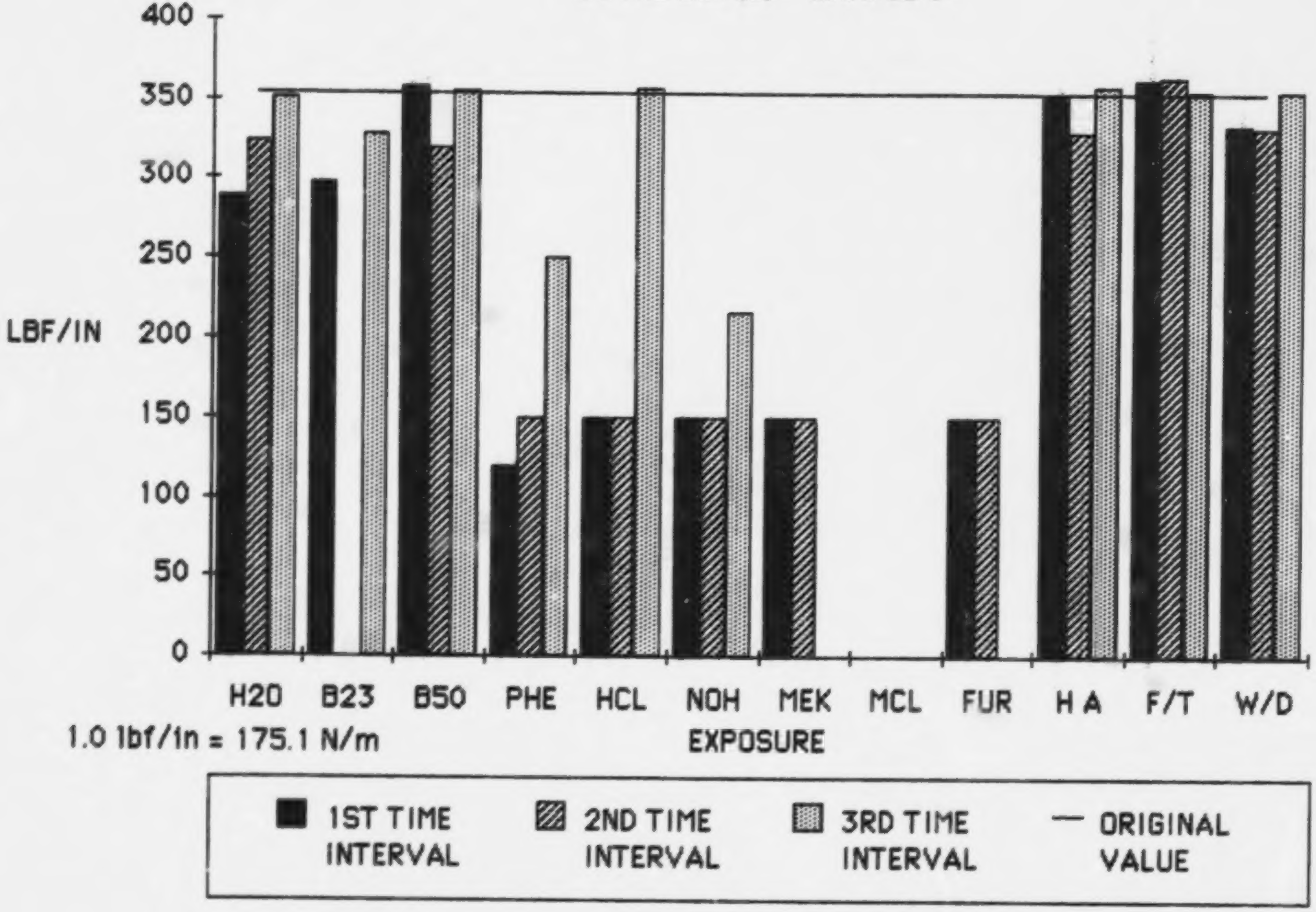


Figure 46. SEAM PEEL STRENGTH - THERMAL HOT AIR FACTORY SEAM - 38 MIL EIA (S) - SAMPLE 9

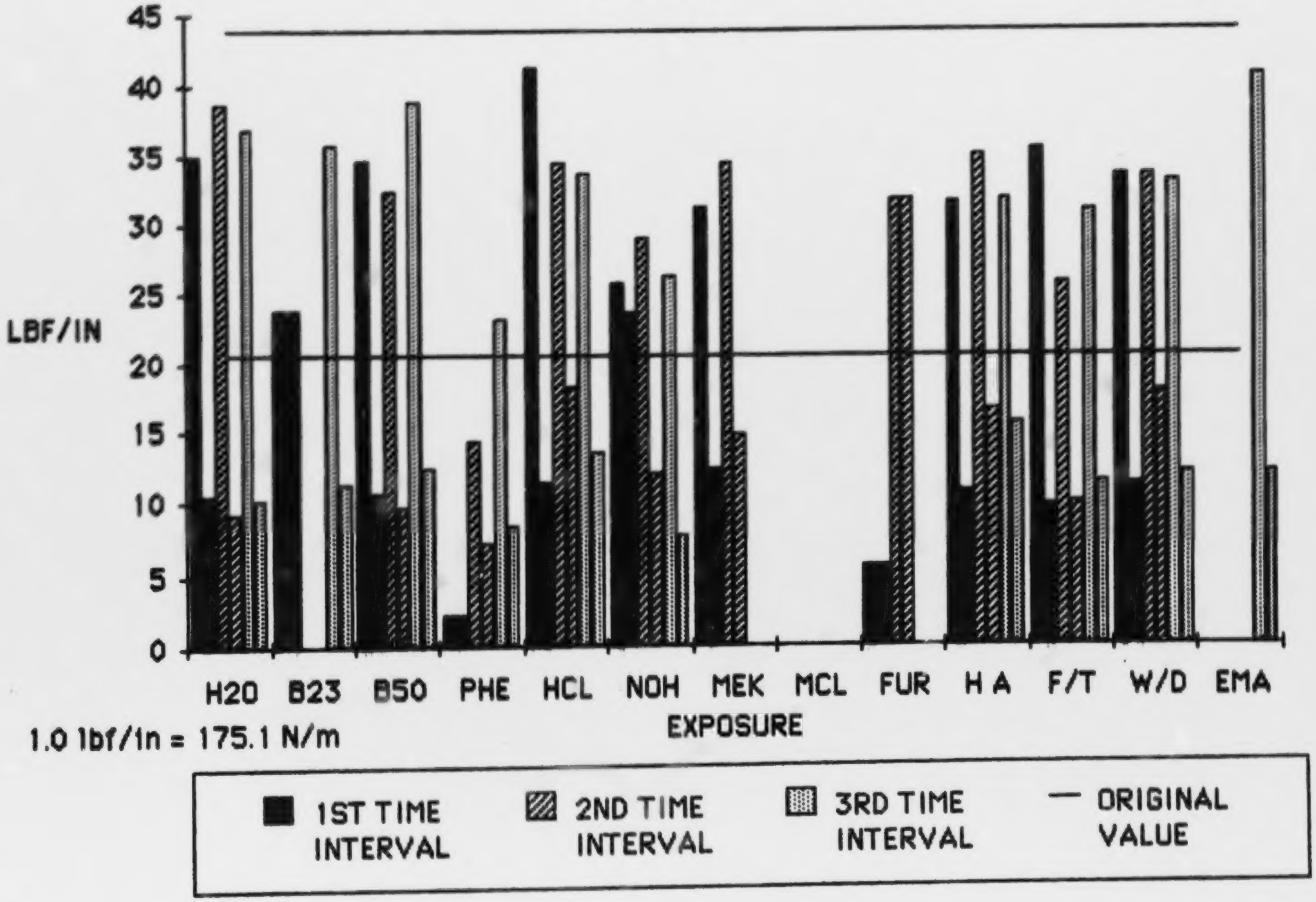


Figure 47. SEAM SHEAR STRENGTH - VULCANIZED FACTORY SEAM - 40 MIL EPDM (S) - SAMPLE 10

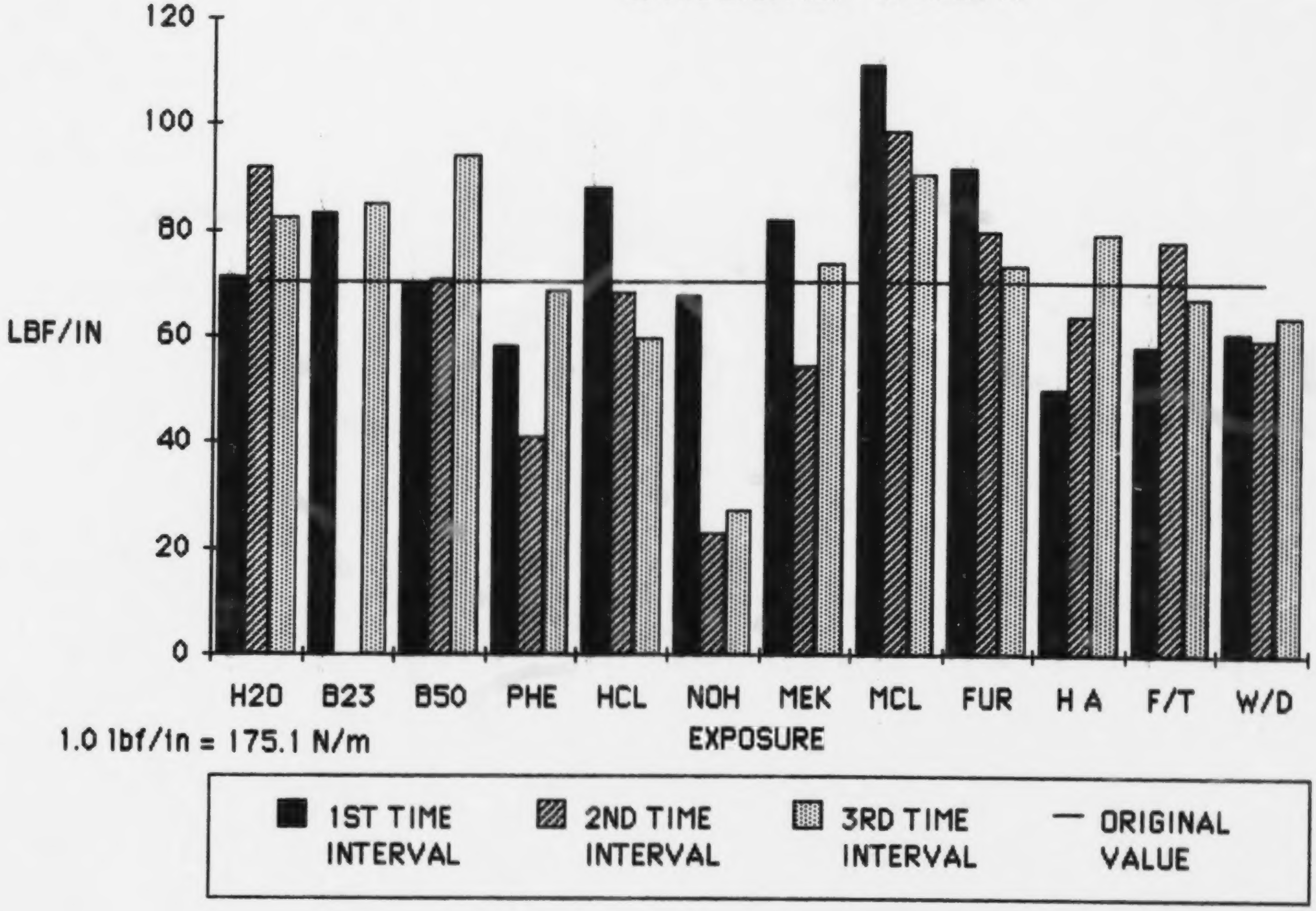
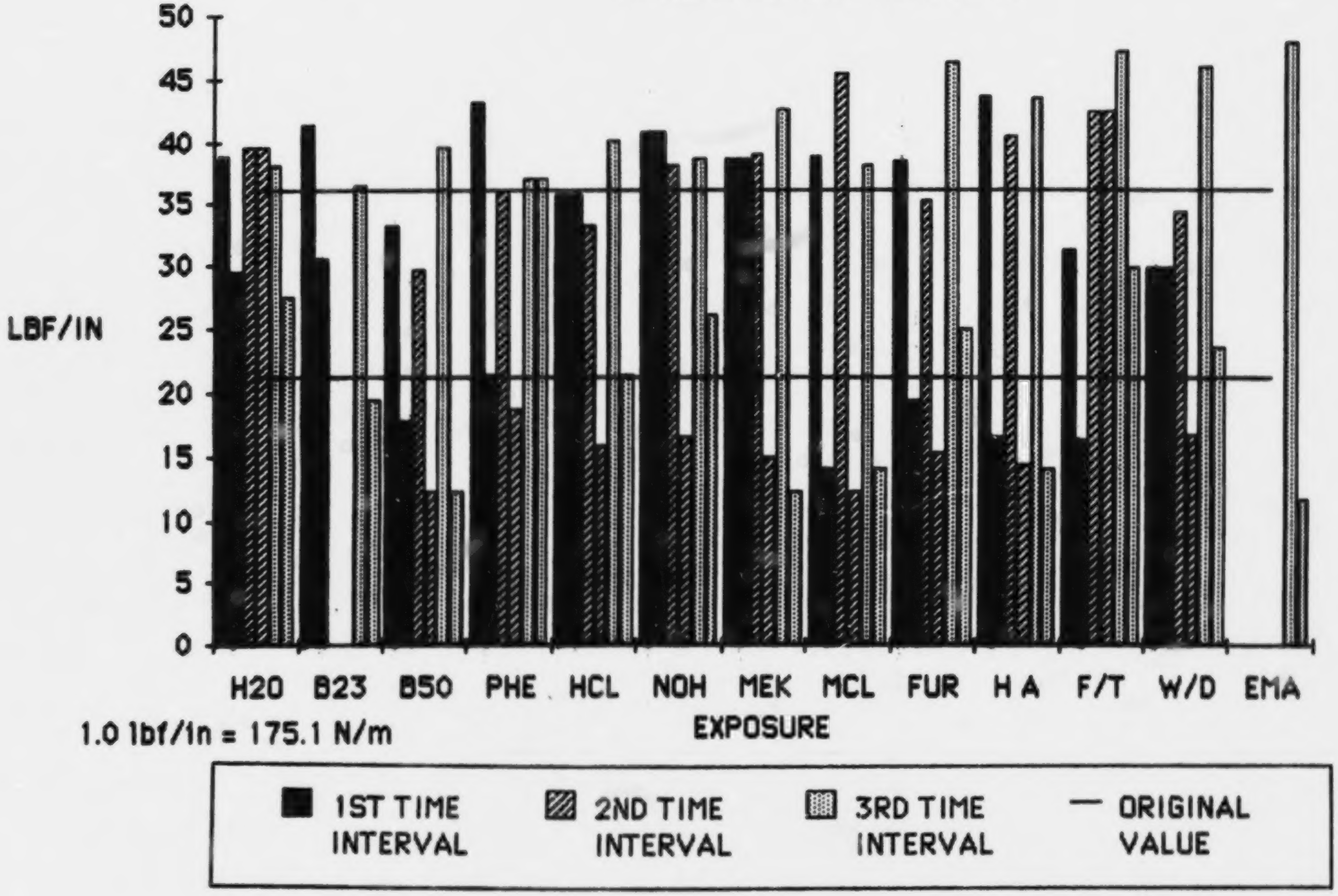


Figure 48. SEAM PEEL STRENGTH - VULCANIZED FACTORY SEAM - 40 MIL EPDM (S) - SAMPLE 10



1.0 lbf/in = 175.1 N/m

Figure 49. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FACTORY SEAM - 30 MIL CPE (U) - SAMPLE 11

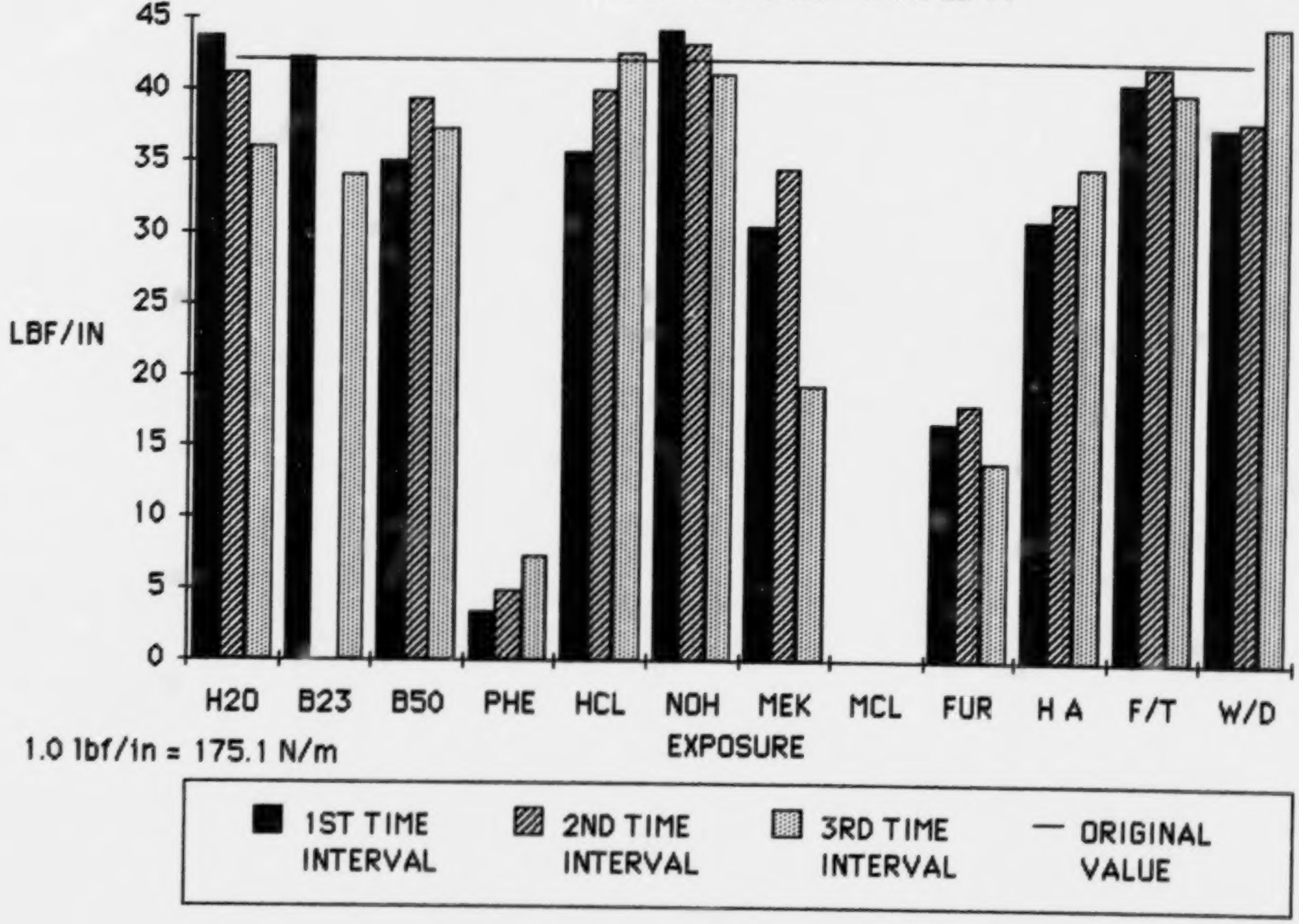


Figure 50. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FACTORY SEAM - 30 MIL CPE (U) - SAMPLE 11

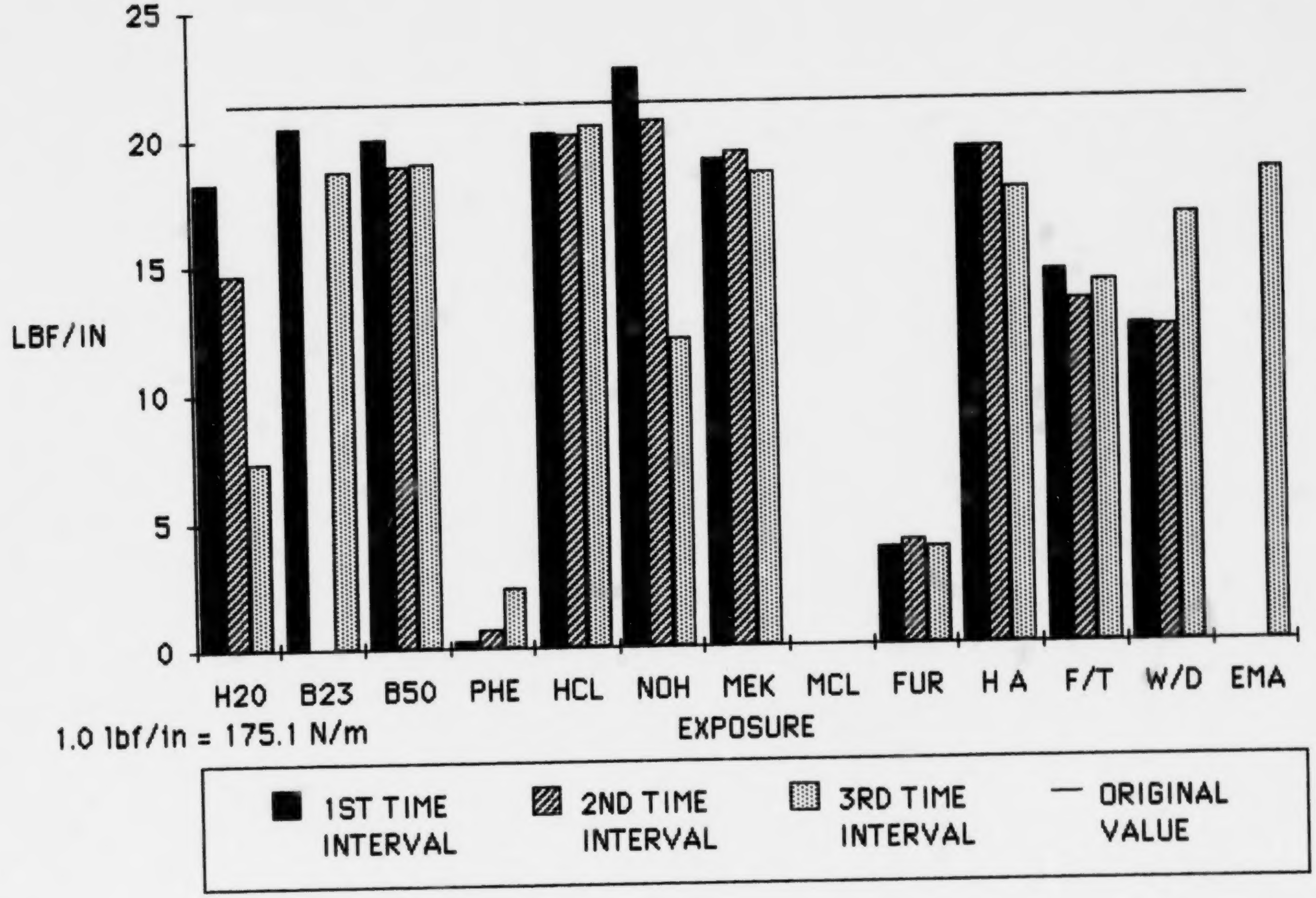
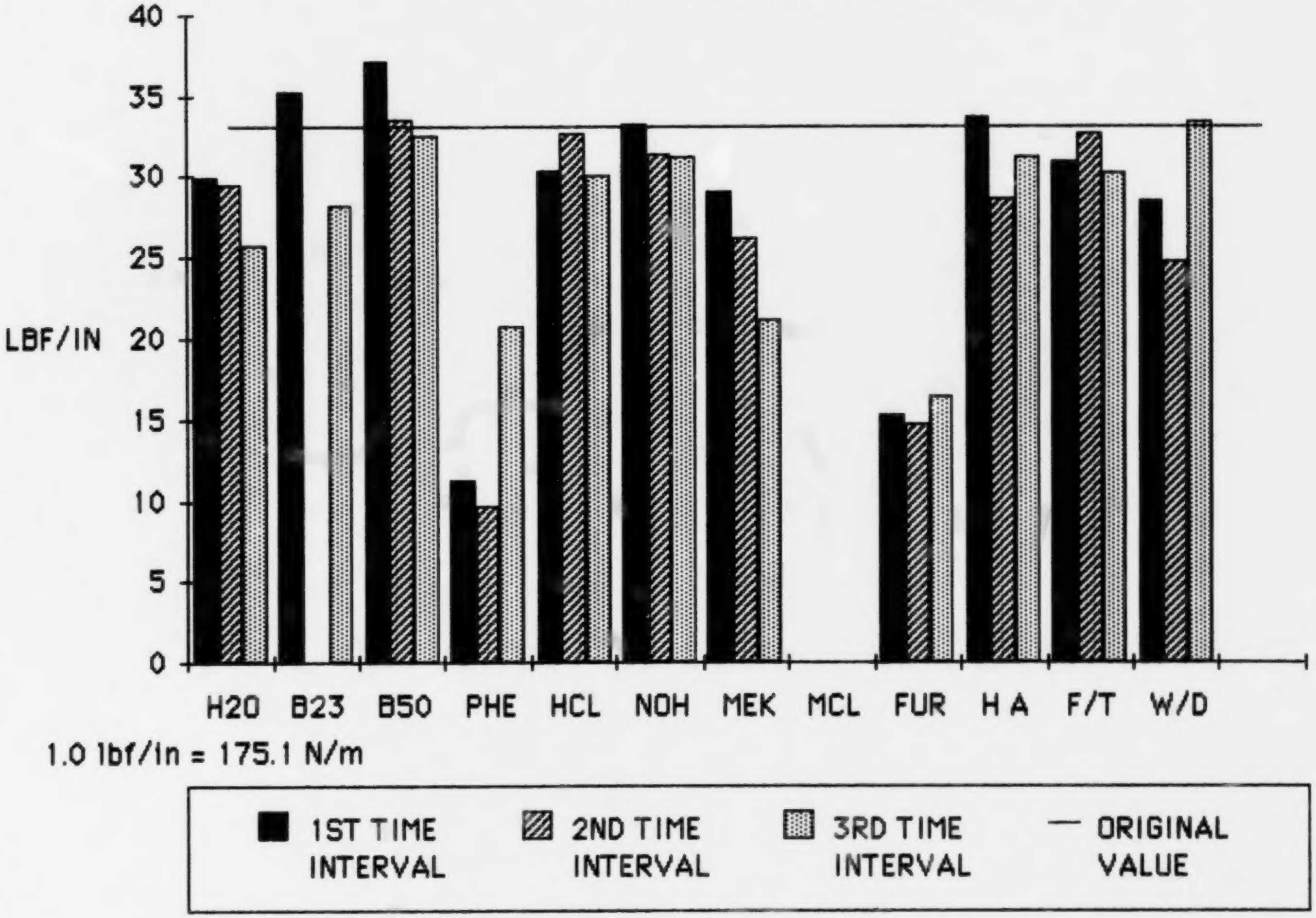


Figure 51. SEAM SHEAR STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 30 MIL CPE (U) - SAMPLE 12



1.0 lbf/in = 175.1 N/m

Figure 52. **SEAM PEEL STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 30 MIL CPE (U) - SAMPLE 12**

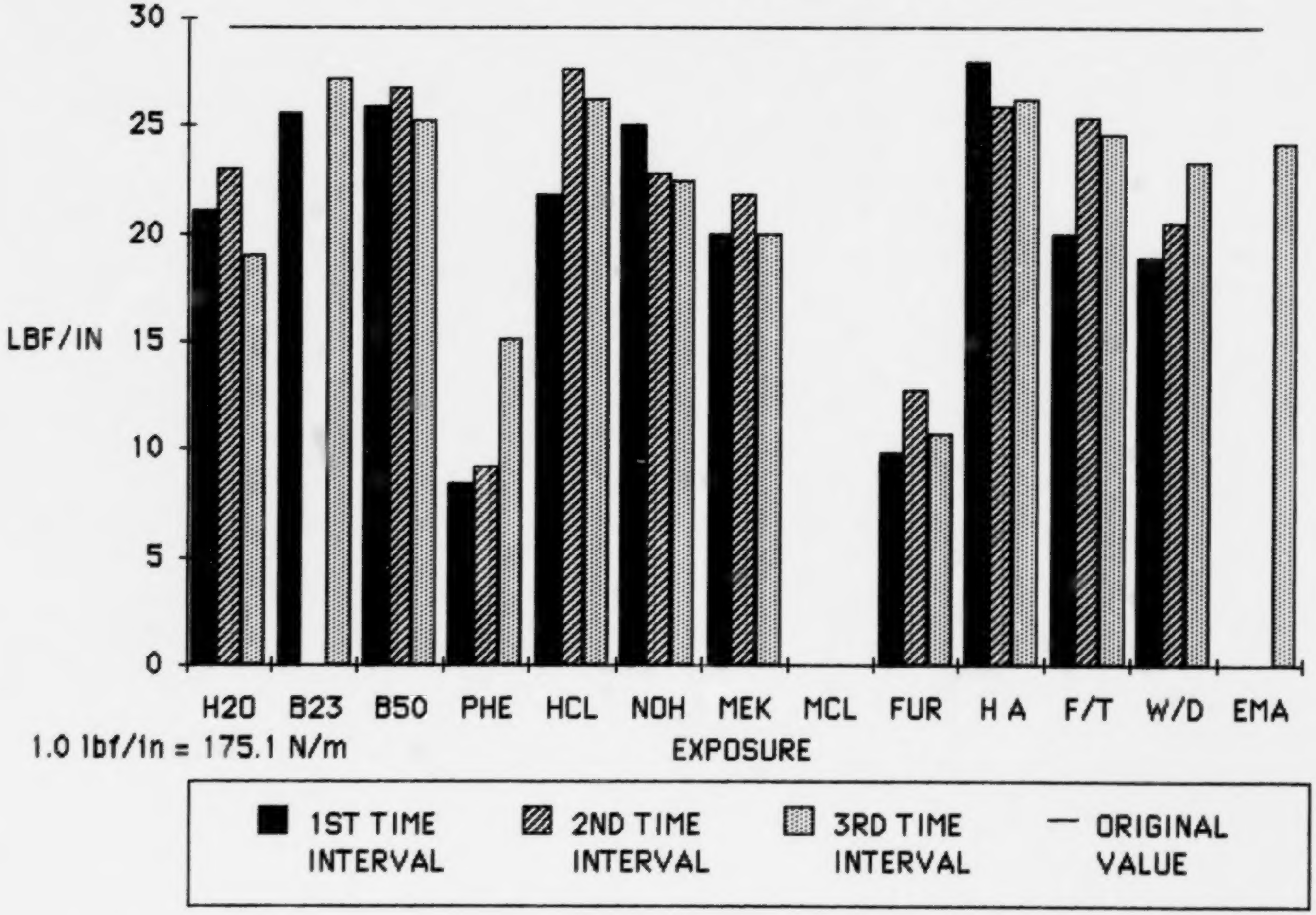
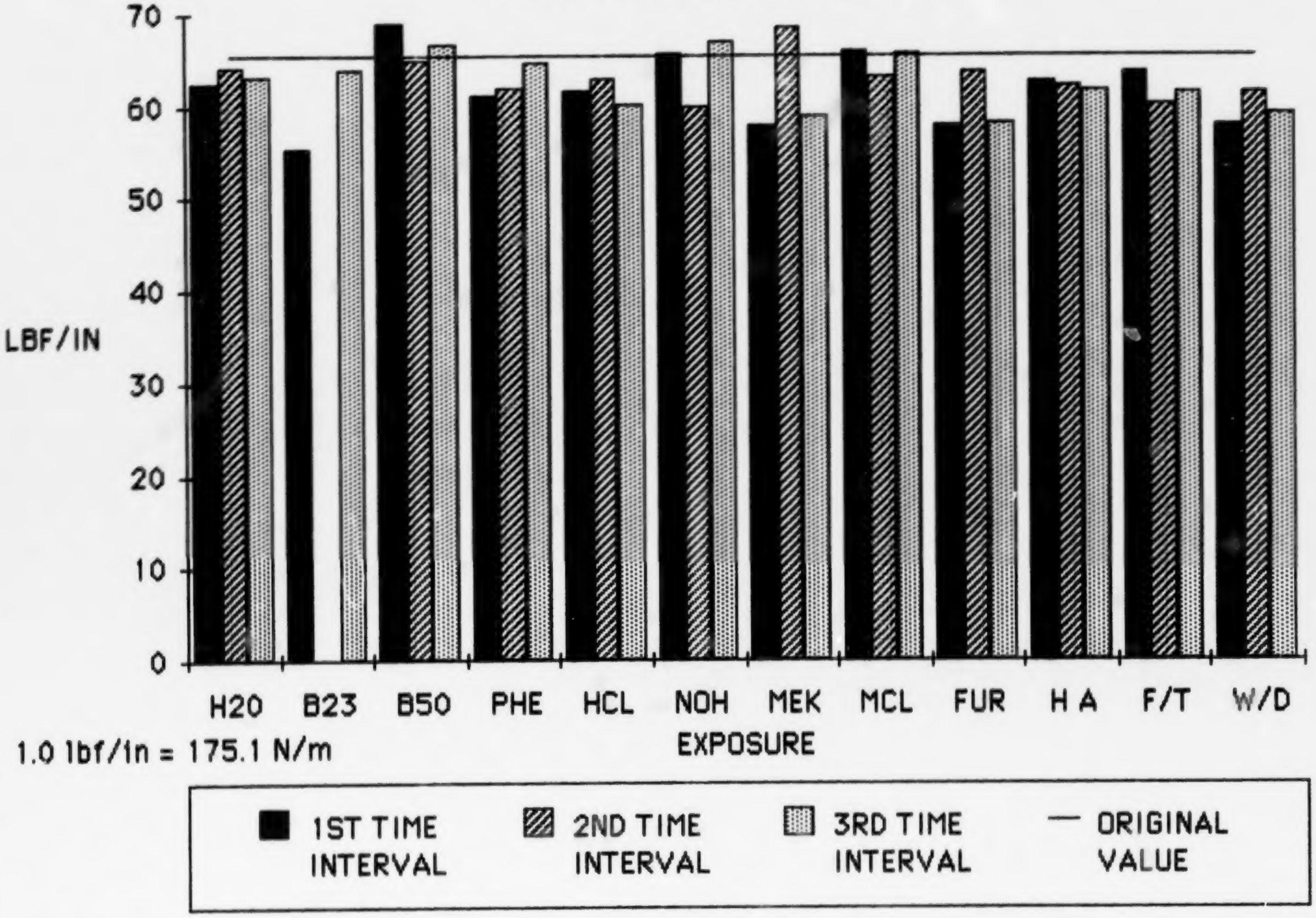


Figure 53. SEAM SHEAR STRENGTH - THERMAL HOT WEDGE FACTORY SEAM - 30 MIL LLDPE (U) - SAMPLE 13



1.0 lbf/in = 175.1 N/m

Figure 54. SEAM PEEL STRENGTH - THERMAL HOT WEDGE FACTORY SEAM - 30 MIL LLDPE (U) - SAMPLE 13

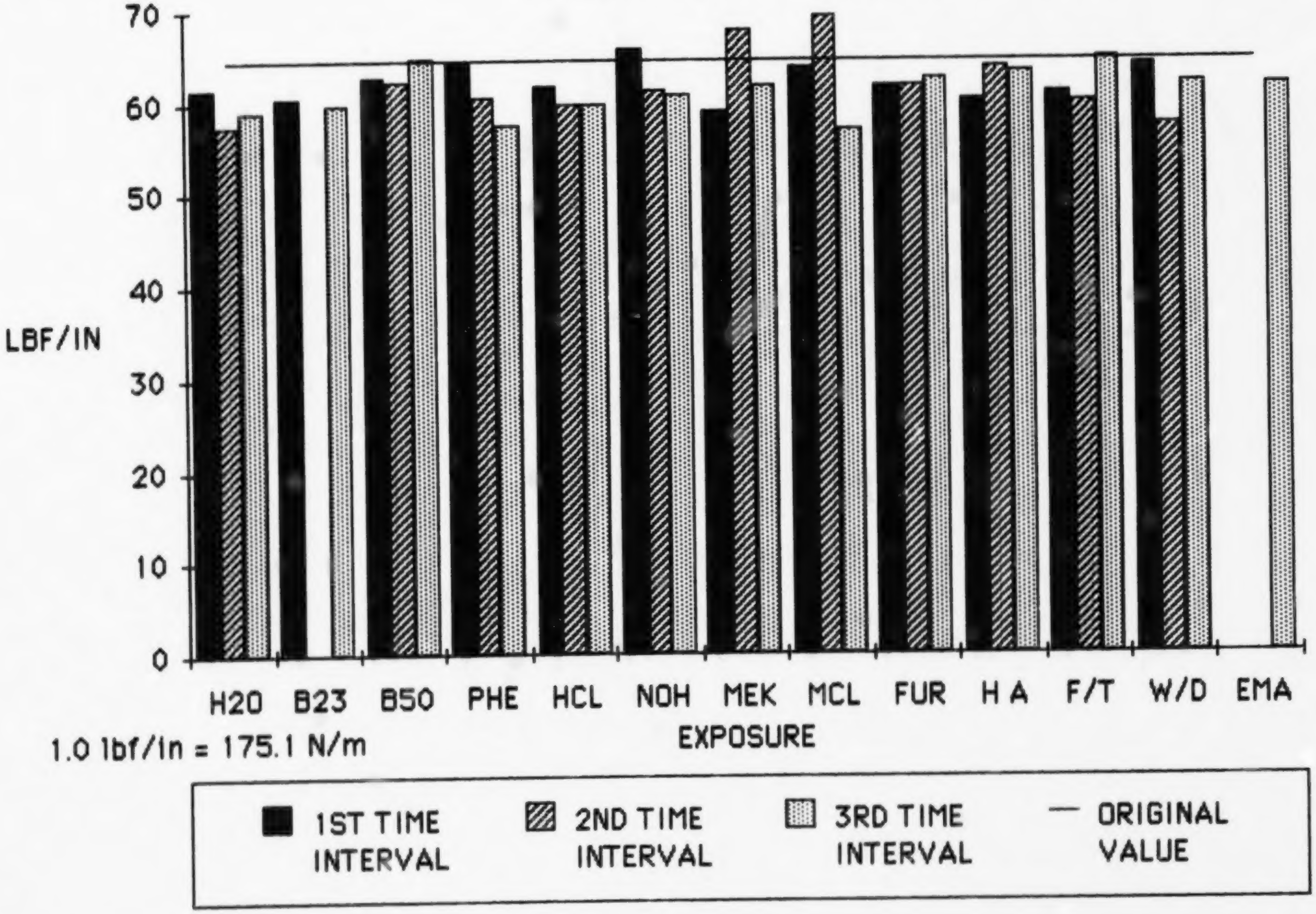


Figure 55. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FACTORY SEAM - 30 MIL PVC (U) - SAMPLE 14

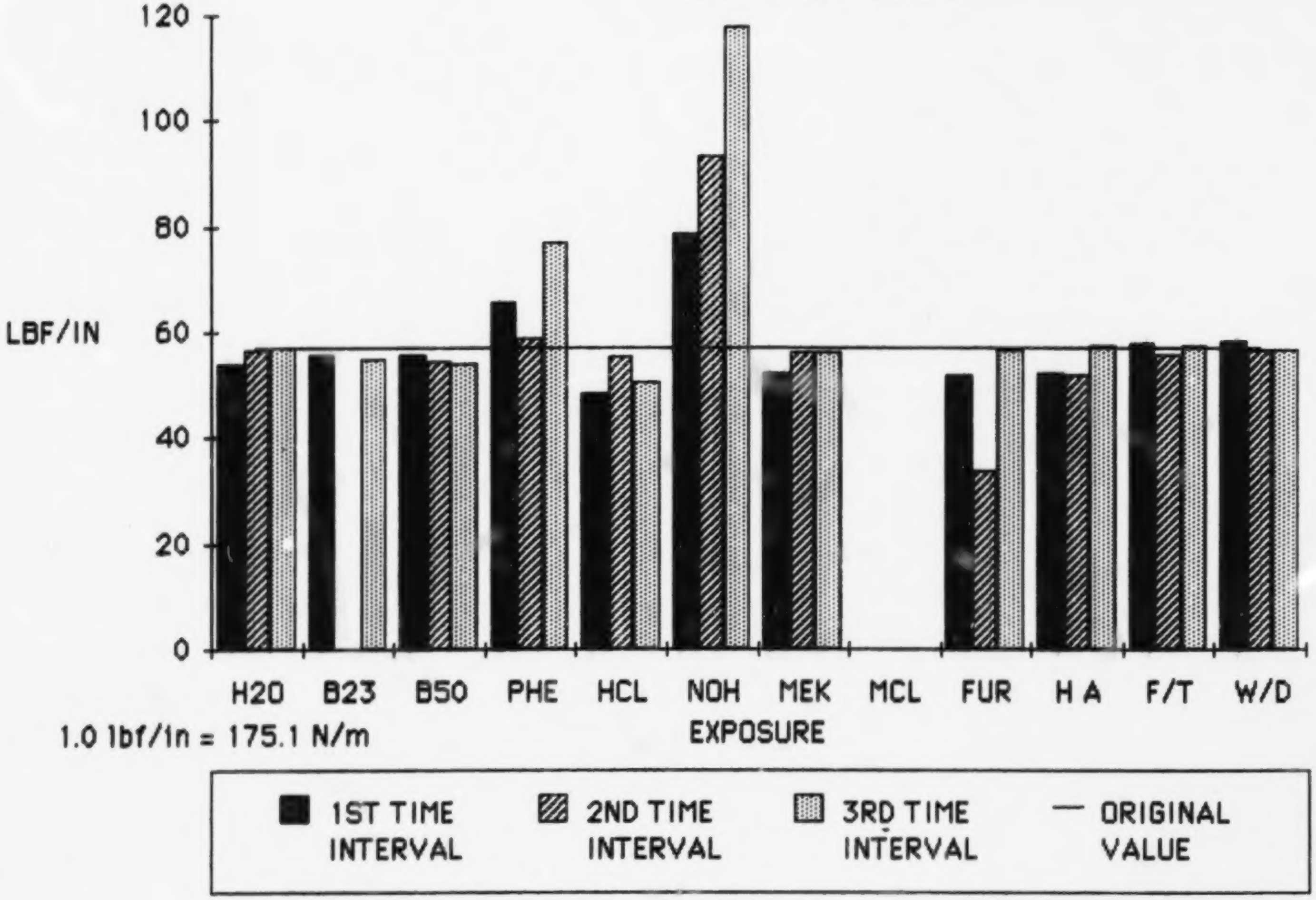


Figure 56. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FACTORY SEAM - 30 MIL PVC (U) - SAMPLE 14

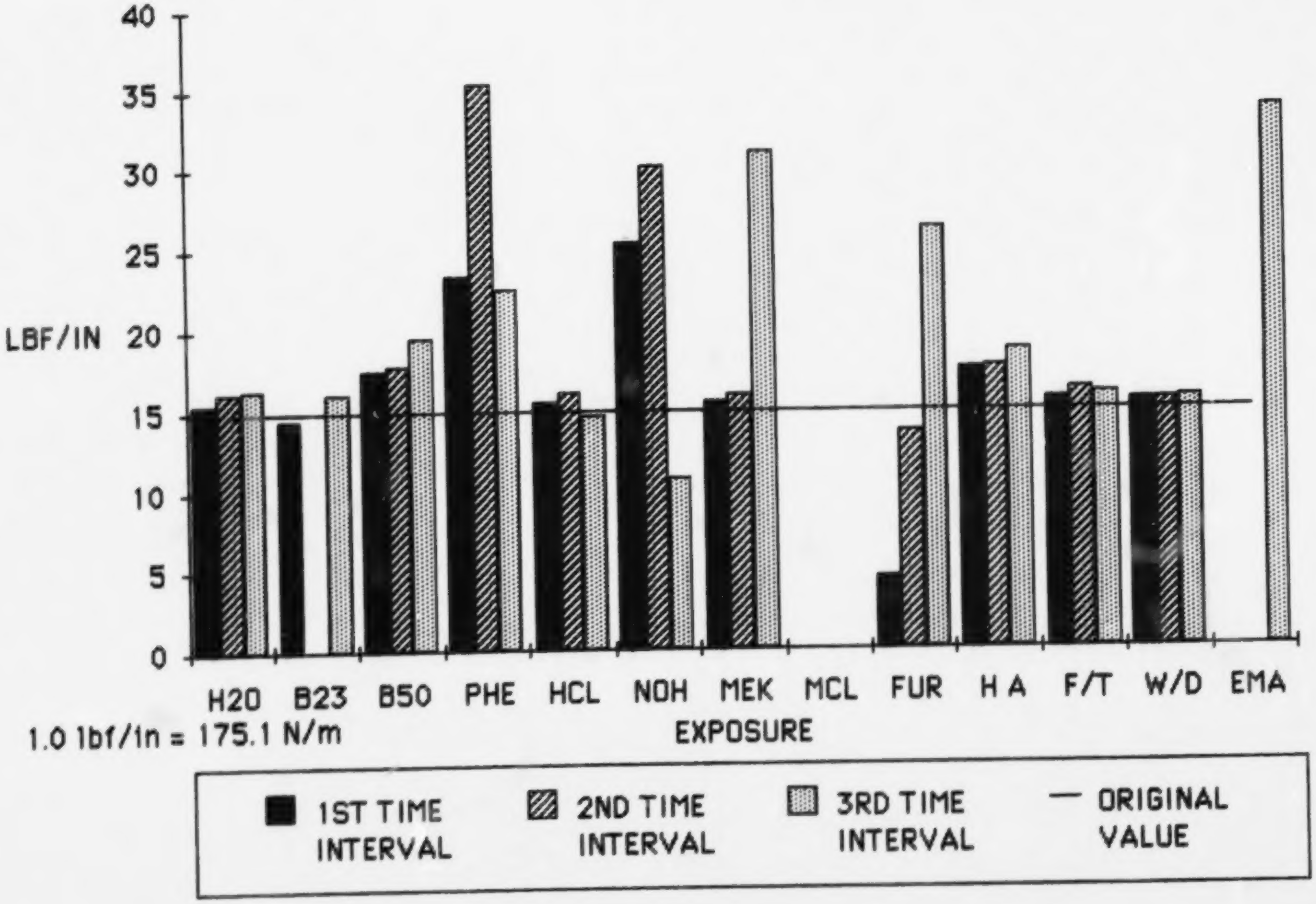
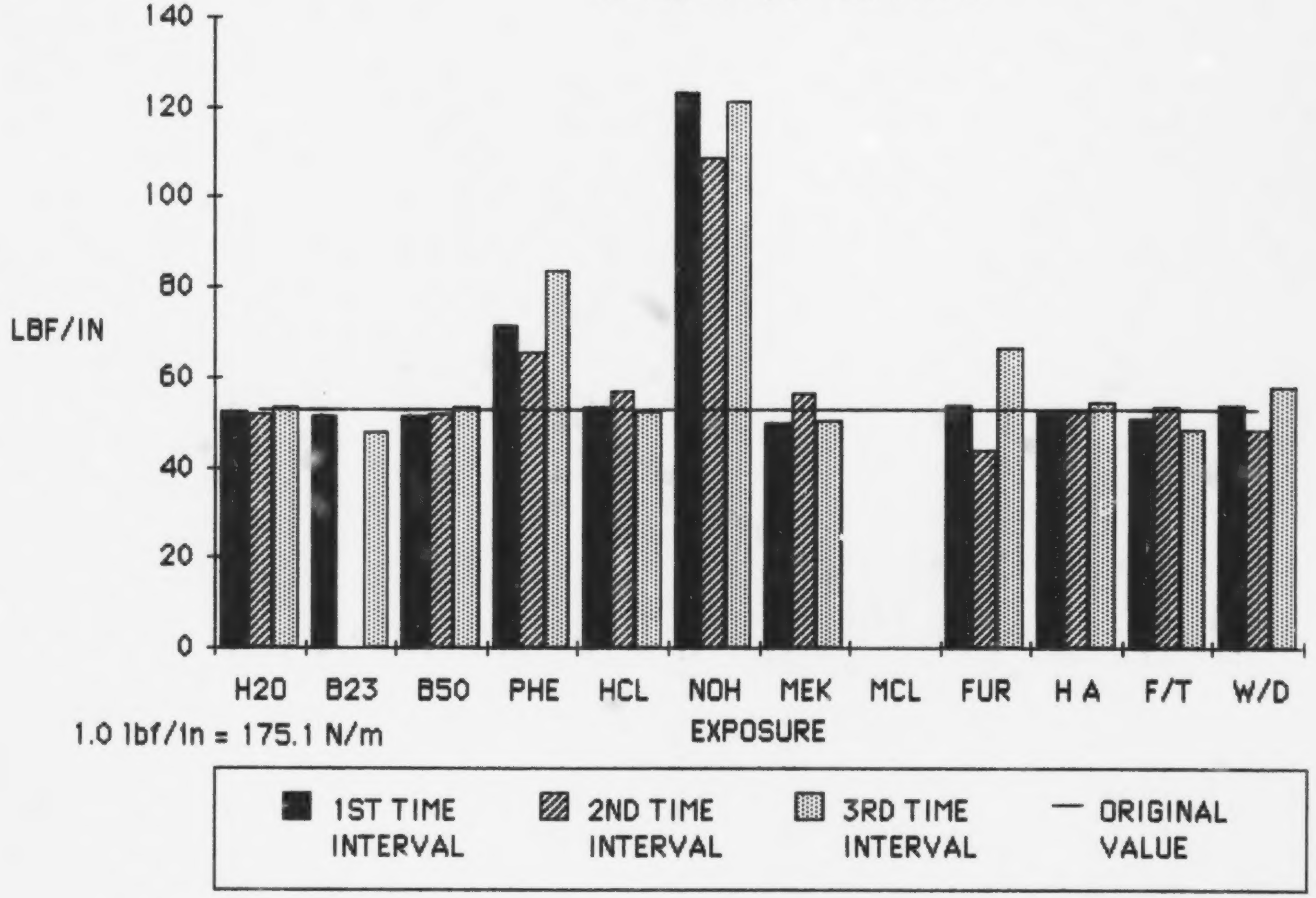
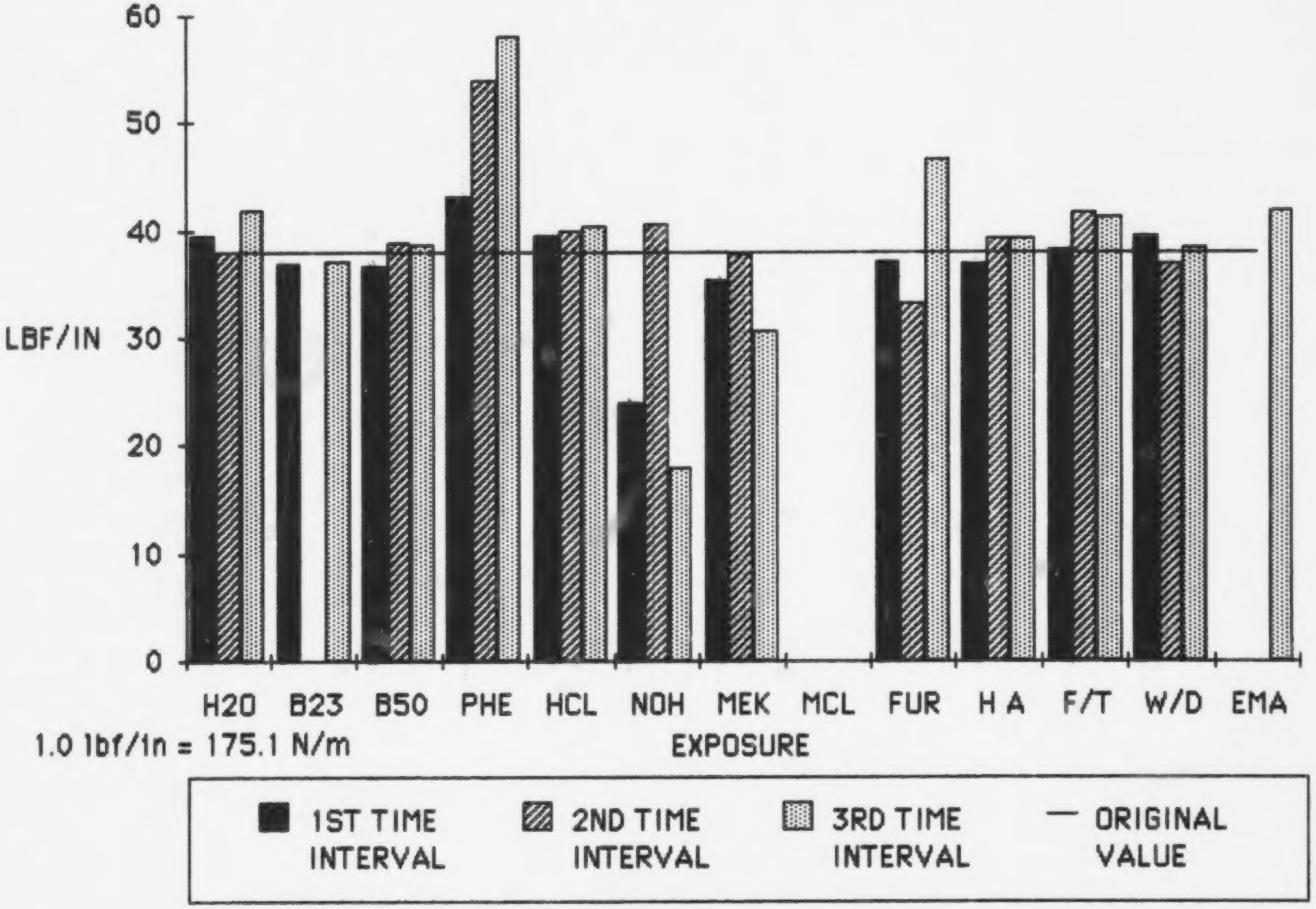


Figure 57. SEAM SHEAR STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 30 MIL PVC (U) - SAMPLE 15



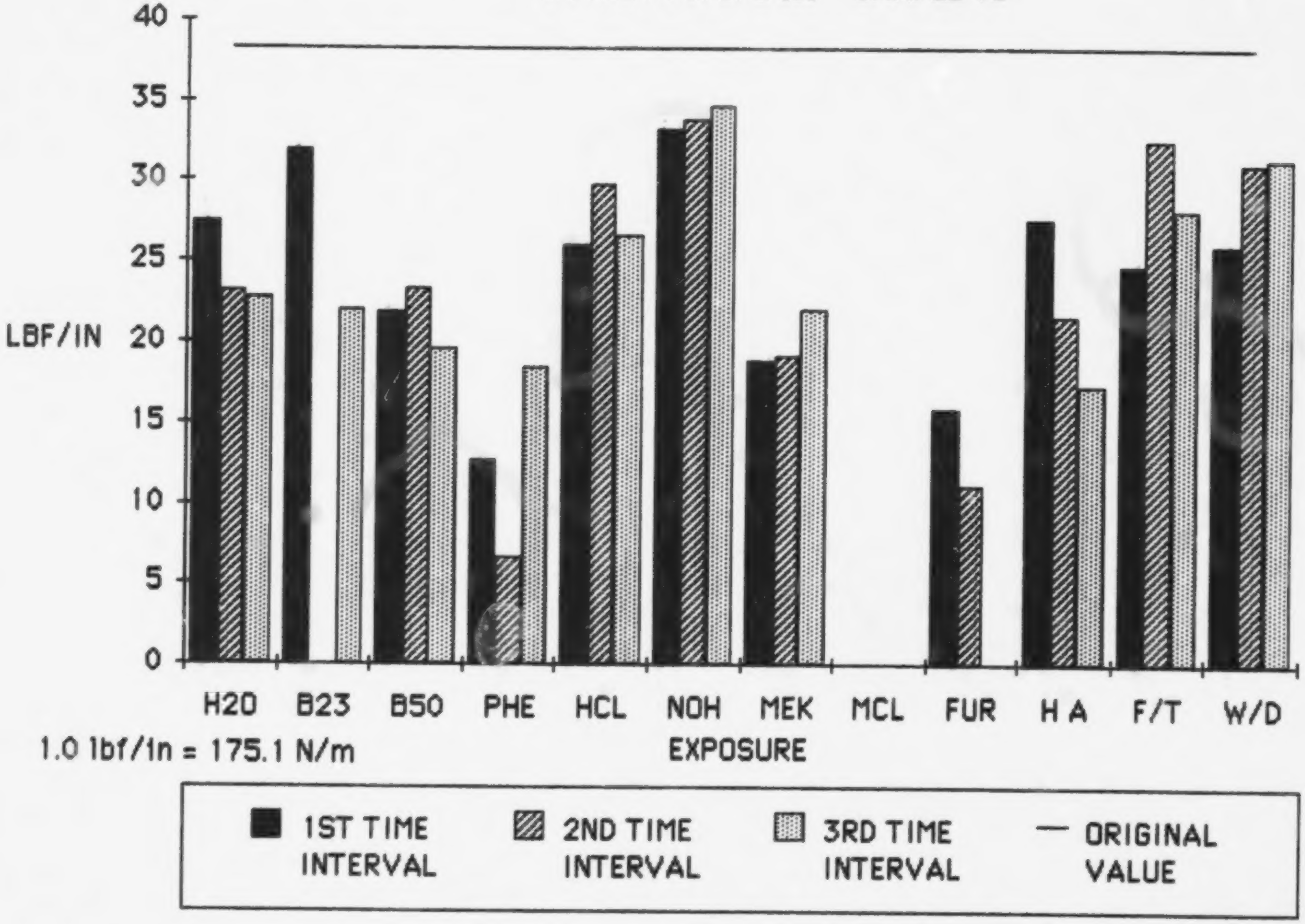
1.0 lbf/in = 175.1 N/m

Figure 58. SEAM PEEL STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 30 MIL PVC (U) - SAMPLE 15



1.0 lbf/in = 175.1 N/m

Figure 59. SEAM SHEAR STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 30 MIL PVC/CPE (U) - SAMPLE 16



1.0 lbf/in = 175.1 N/m

Figure 60. SEAM PEEL STRENGTH - THERMAL DIELECTRIC FACTORY SEAM - 30 MIL PVC/CPE (U) - SAMPLE 16

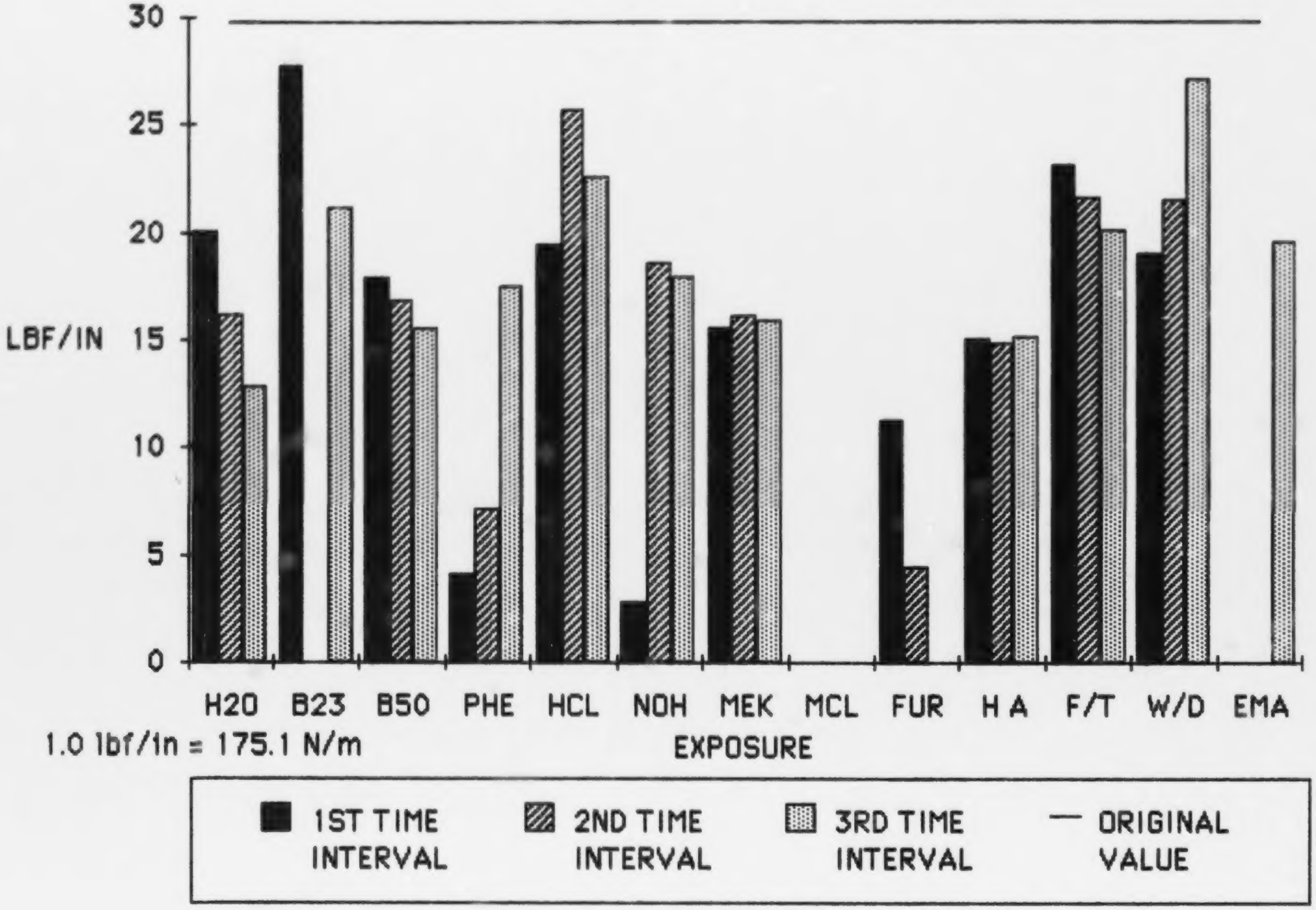
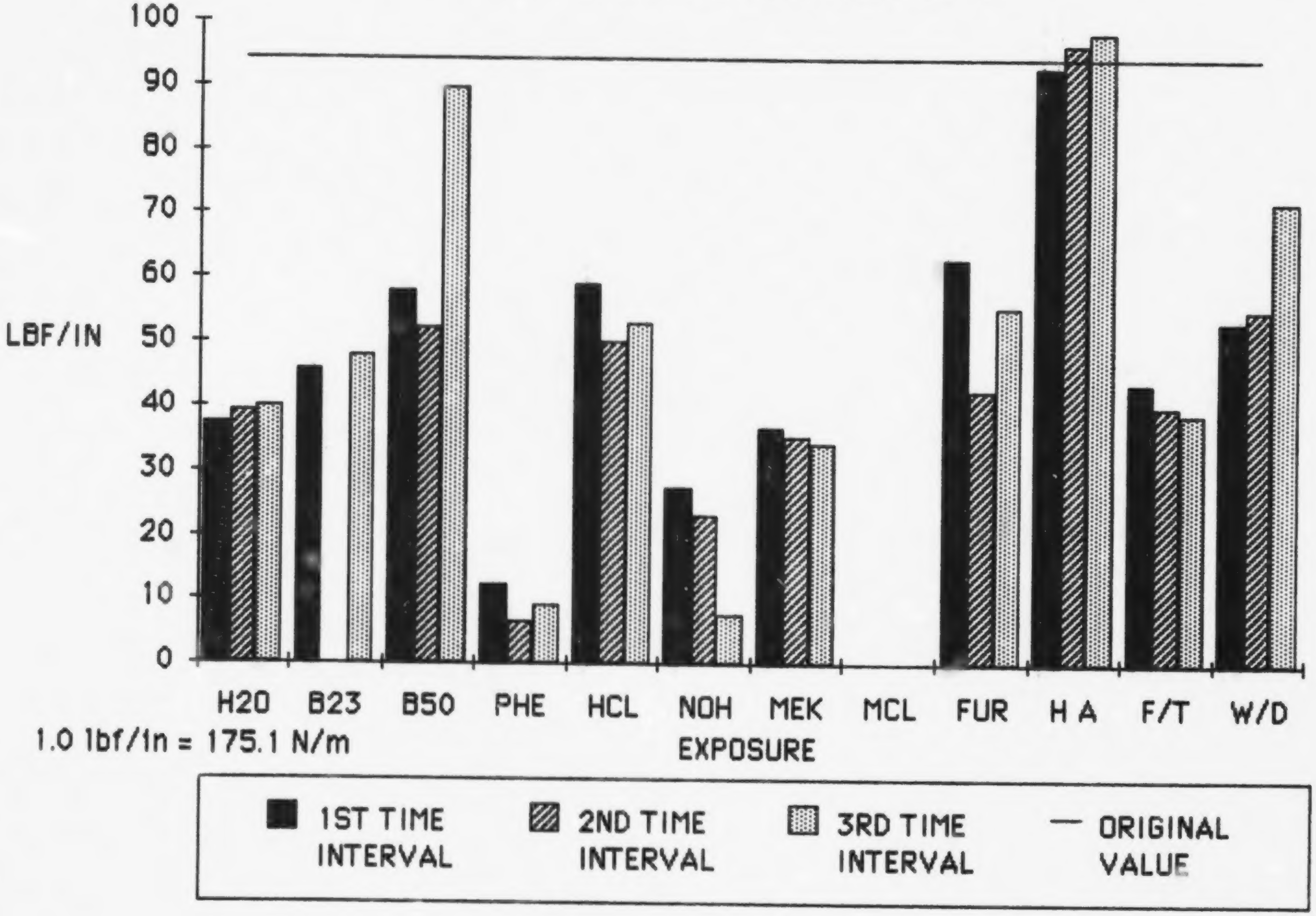
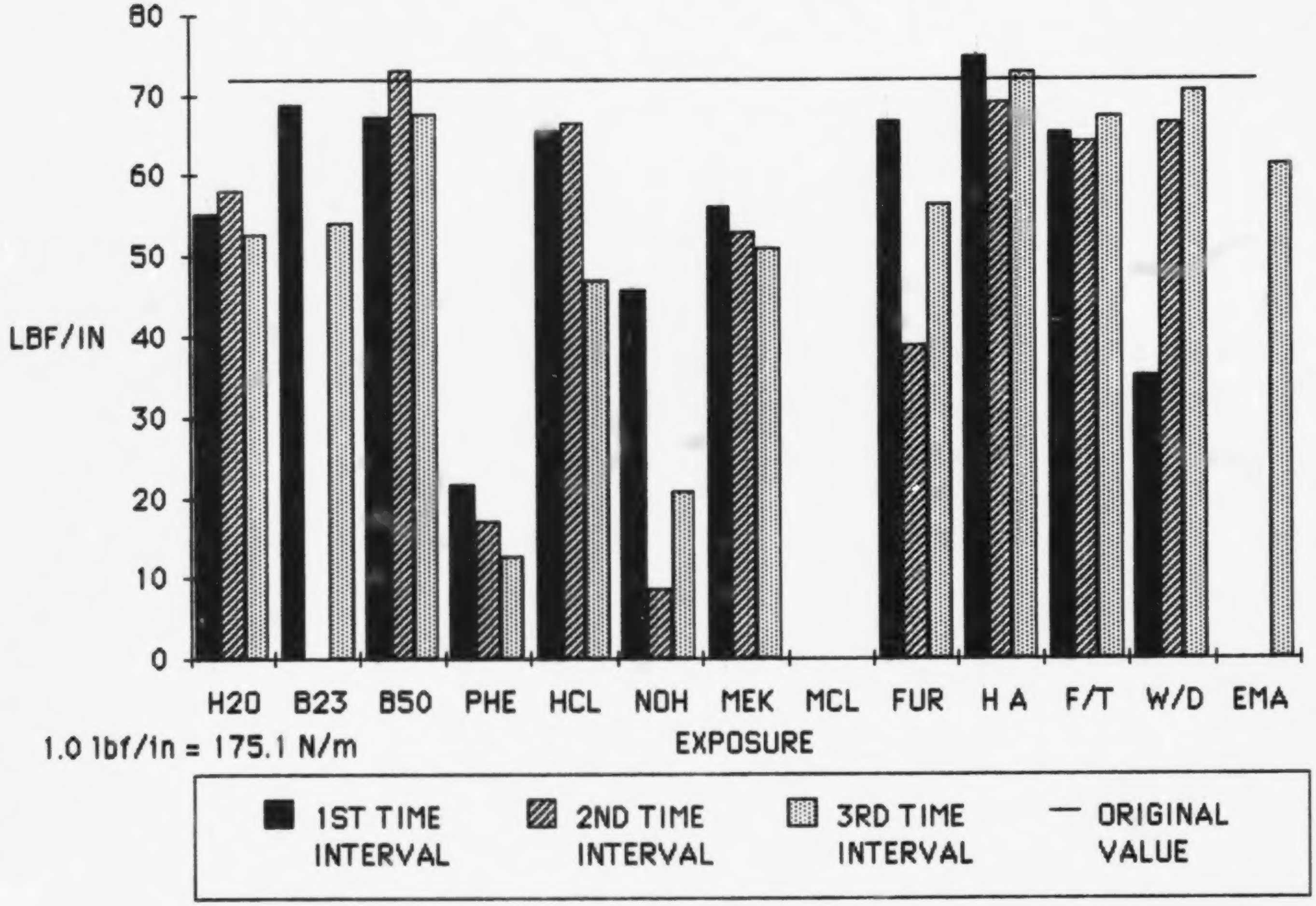


Figure 61. SEAM SHEAR STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 36 MIL CPE (S) - SAMPLE 17



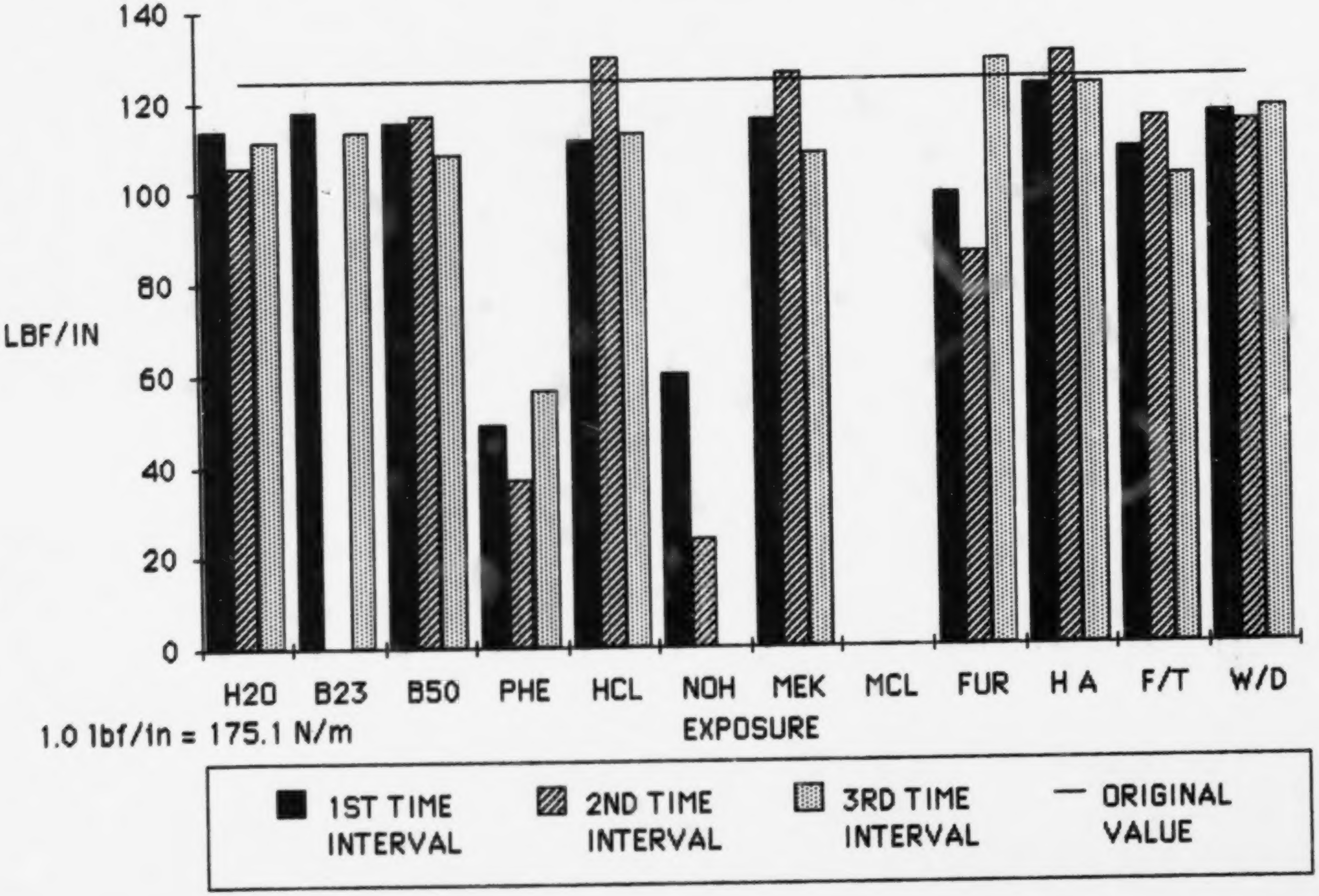
1.0 lbf/in = 175.1 N/m

Figure 62. SEAM PEEL STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 36 MIL CPE (S) - SAMPLE 17



1.0 lbf/in = 175.1 N/m

Figure 63. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CPE (S) - SAMPLE 18



1.0 lbf/in = 175.1 N/m

Figure 64. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CPE (S) - SAMPLE 18

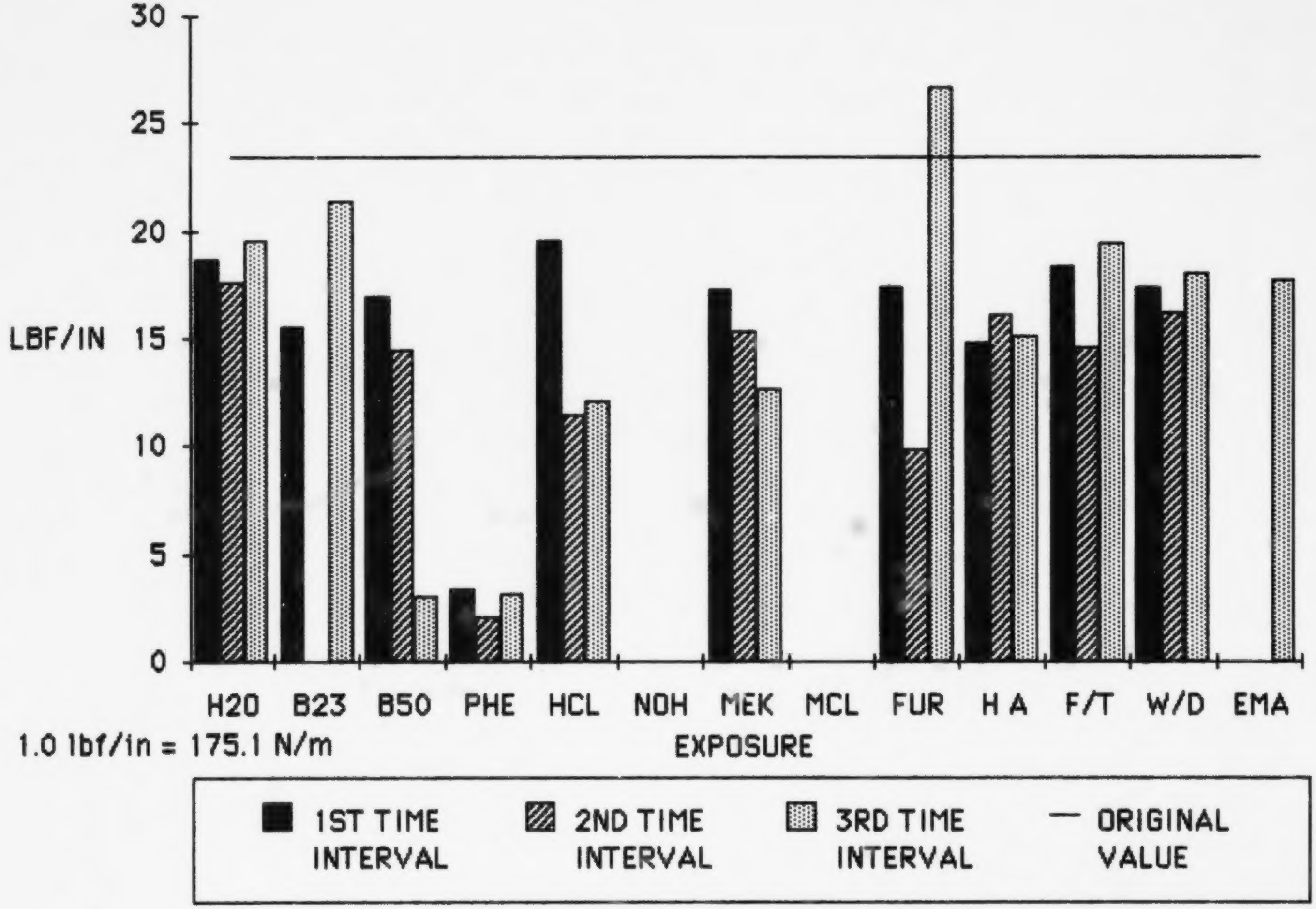


Figure 65. SEAM SHEAR STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 30 MIL CSPE (S) - SAMPLE 19

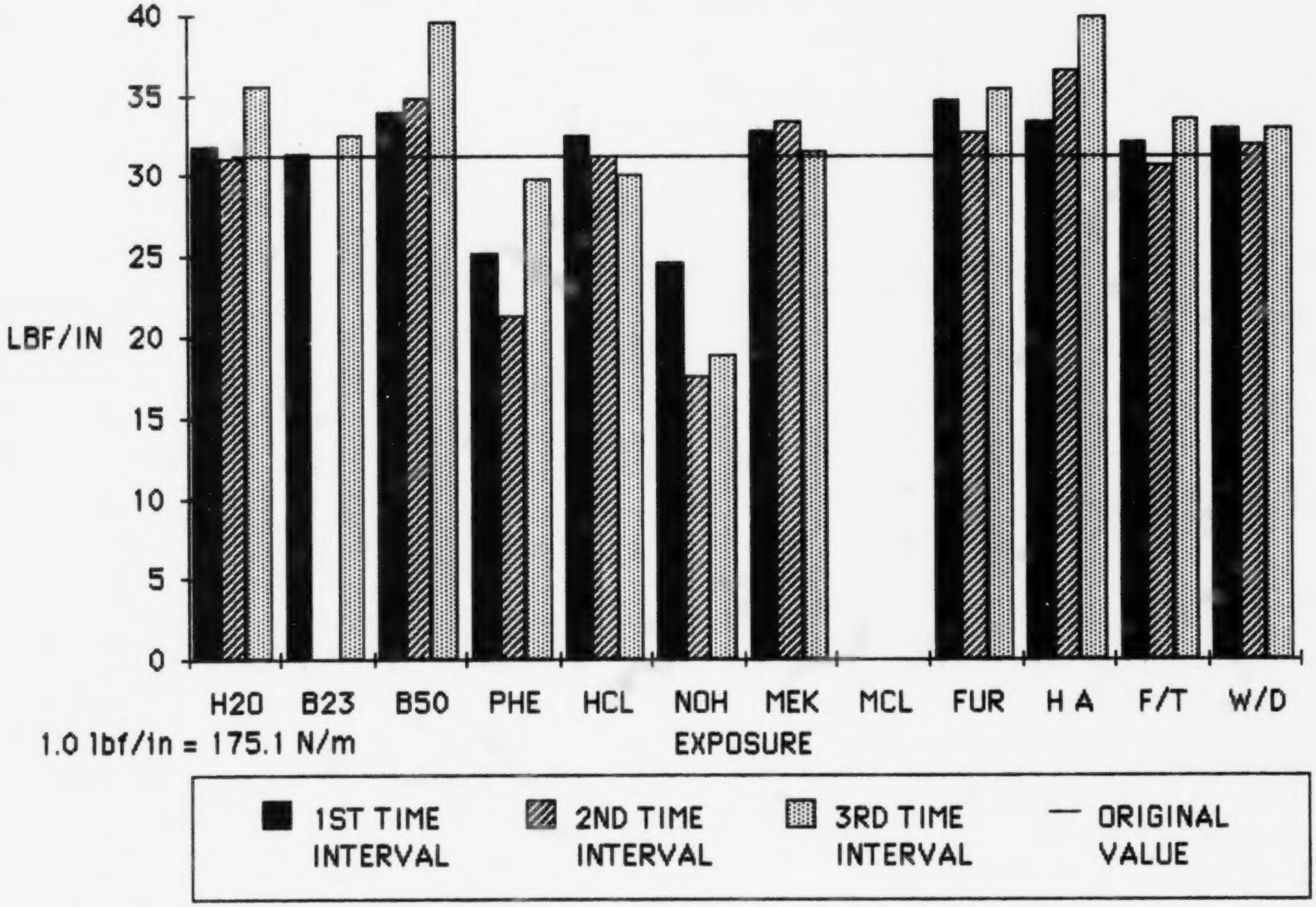


Figure 66. SEAM PEEL STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 30 MIL CSPE (S) - SAMPLE 19

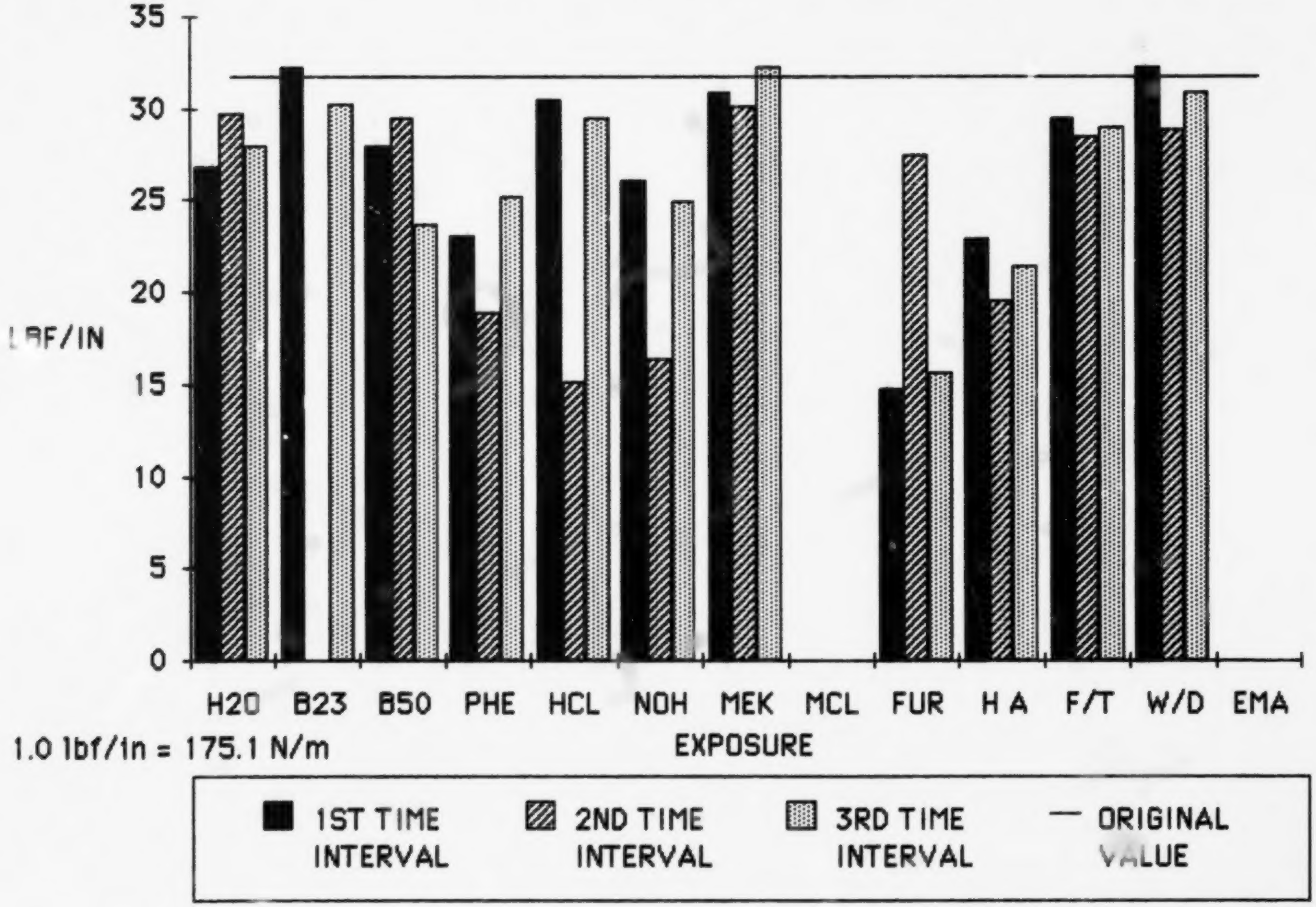


Figure 67. SEAM SHEAR STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 20

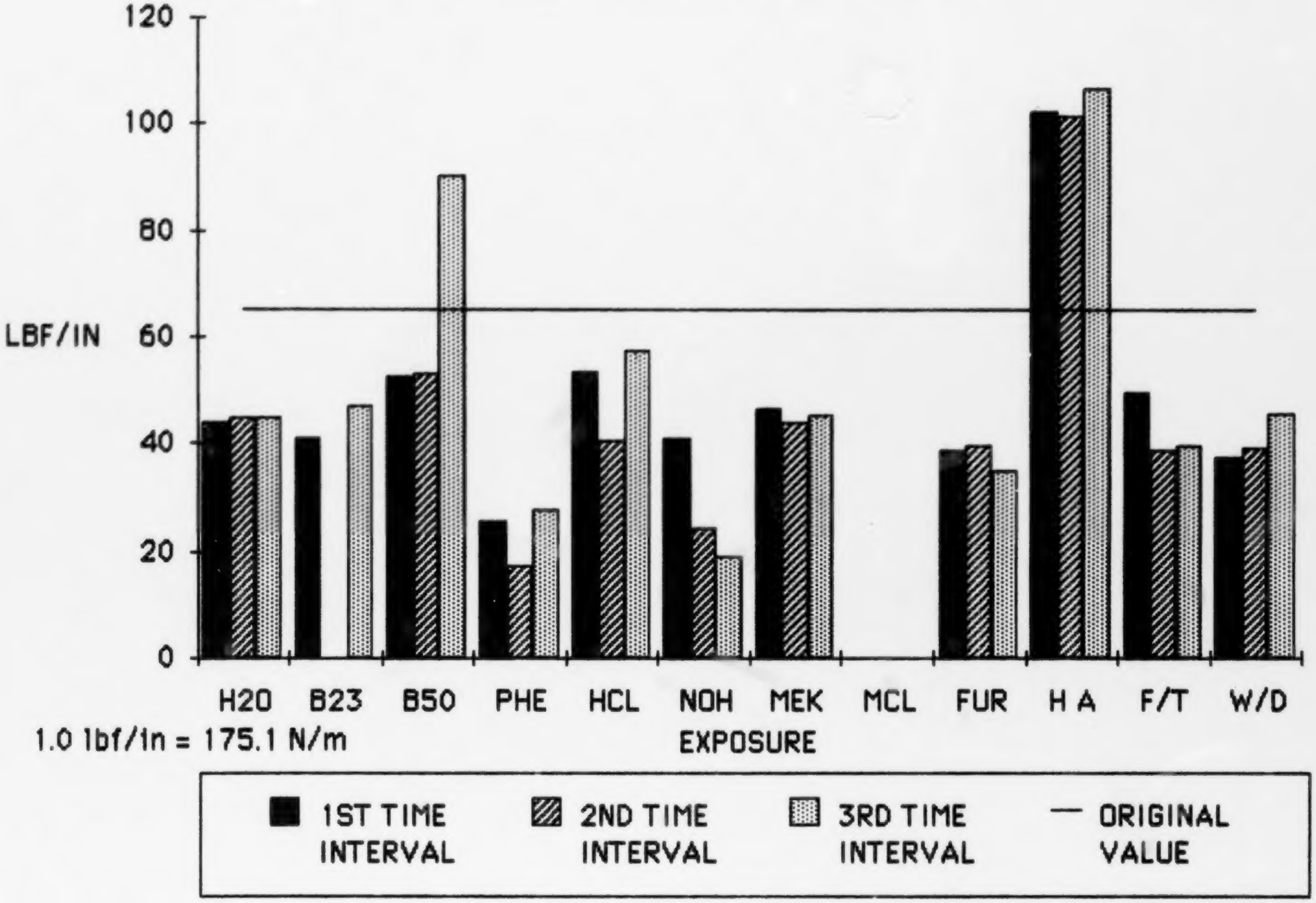


Figure 68. SEAM PEEL STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 20

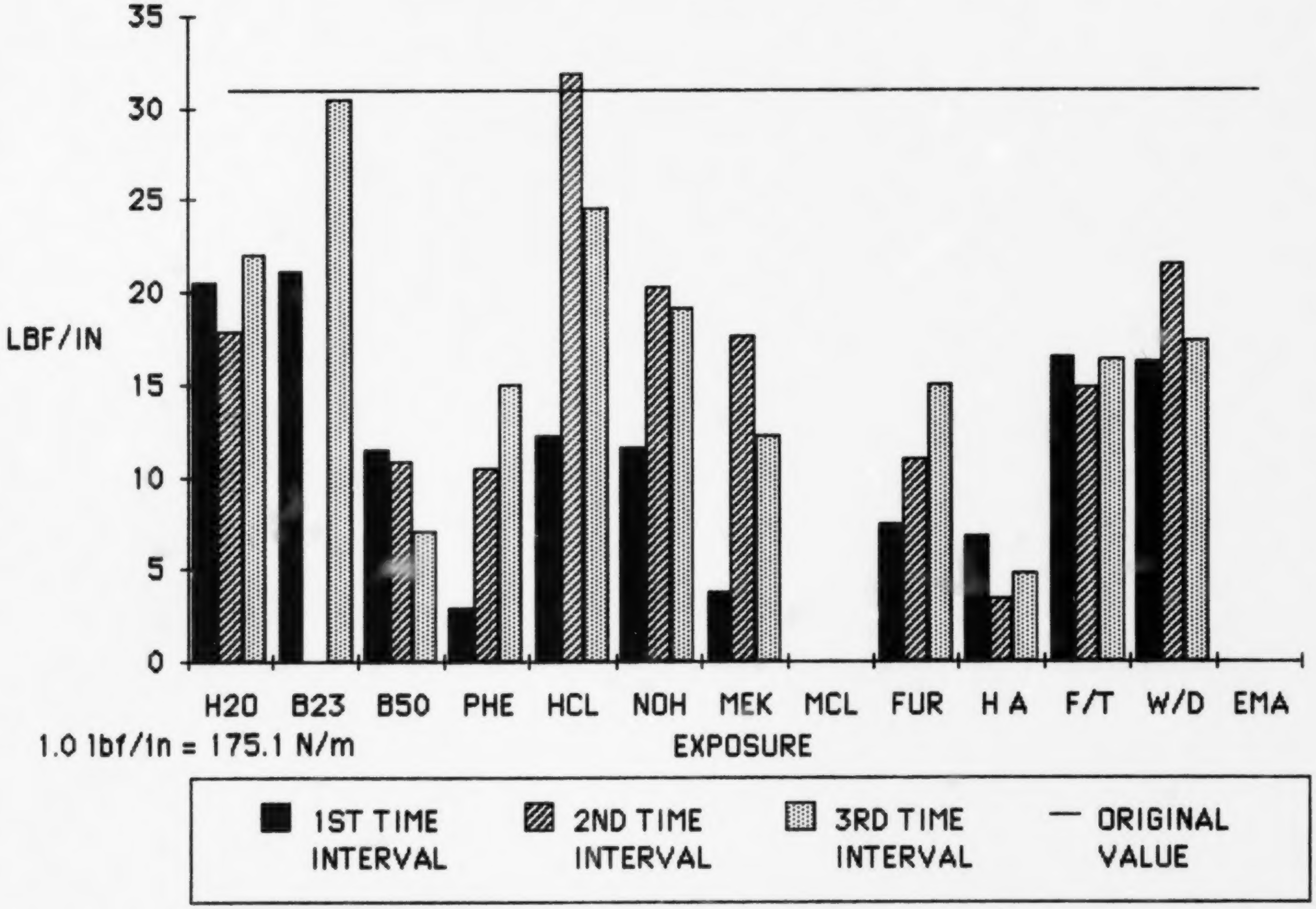


Figure 69. SEAM SHEAR STRENGTH - ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 21

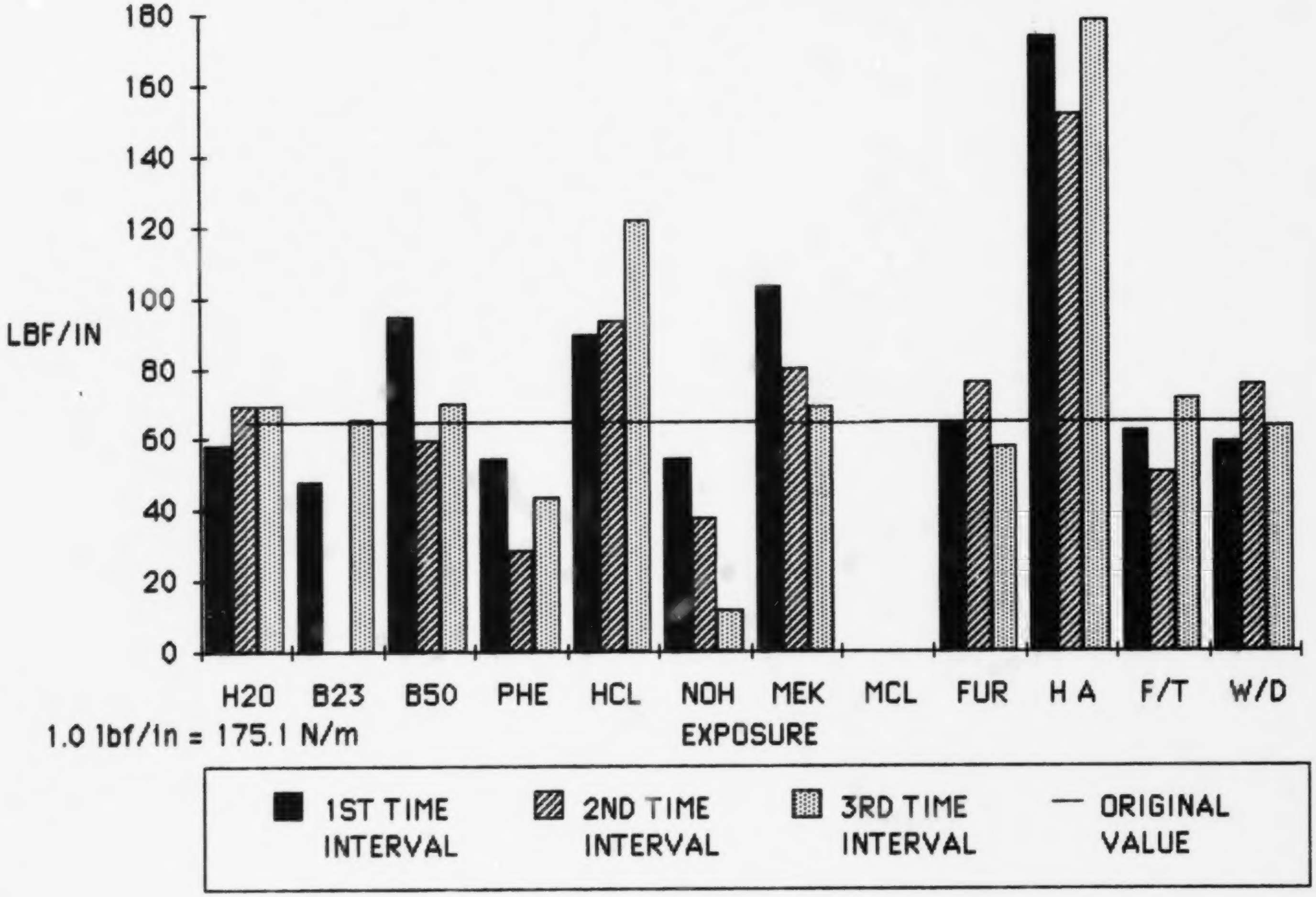


Figure 70. SEAM PEEL STRENGTH - ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 21

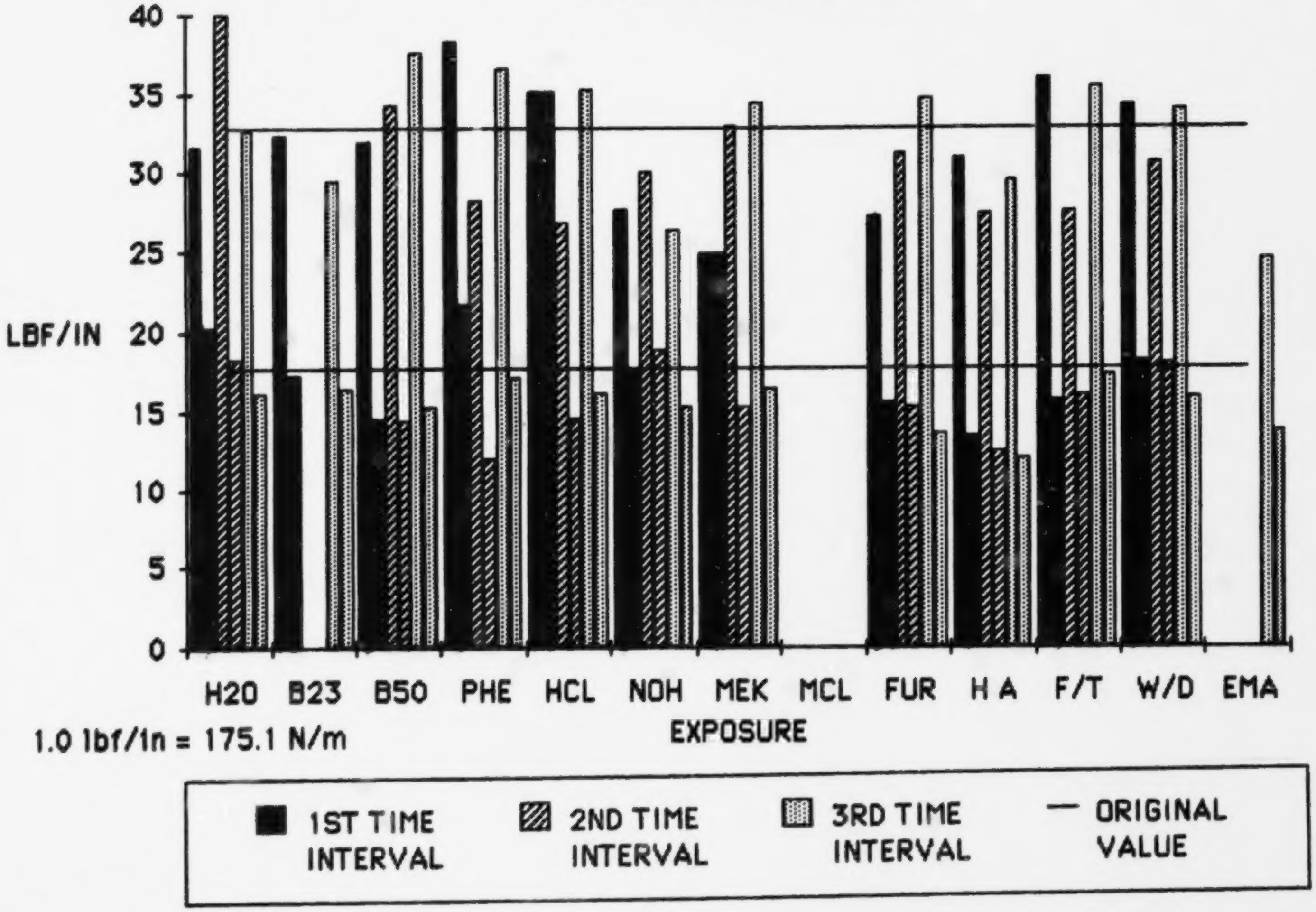
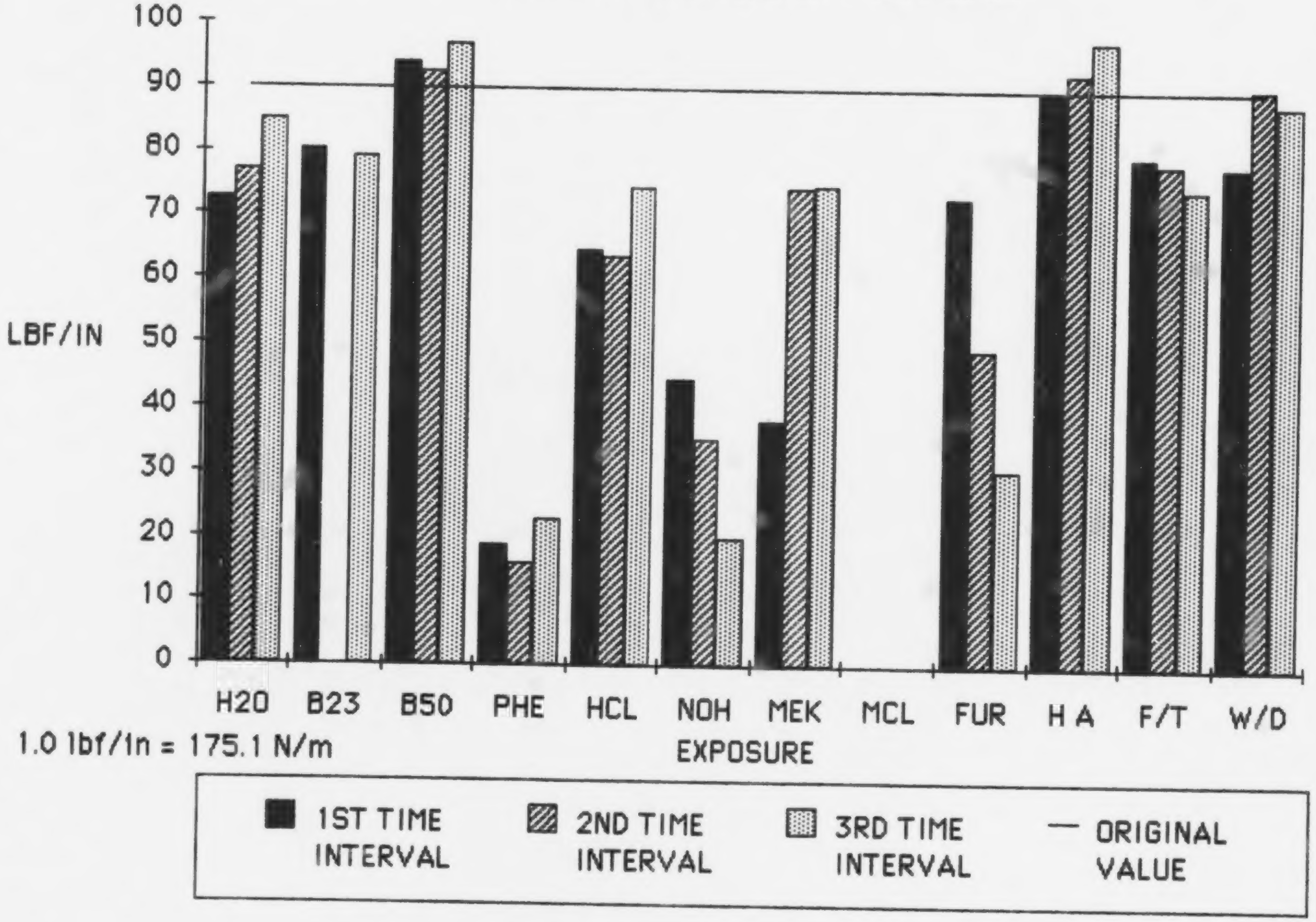
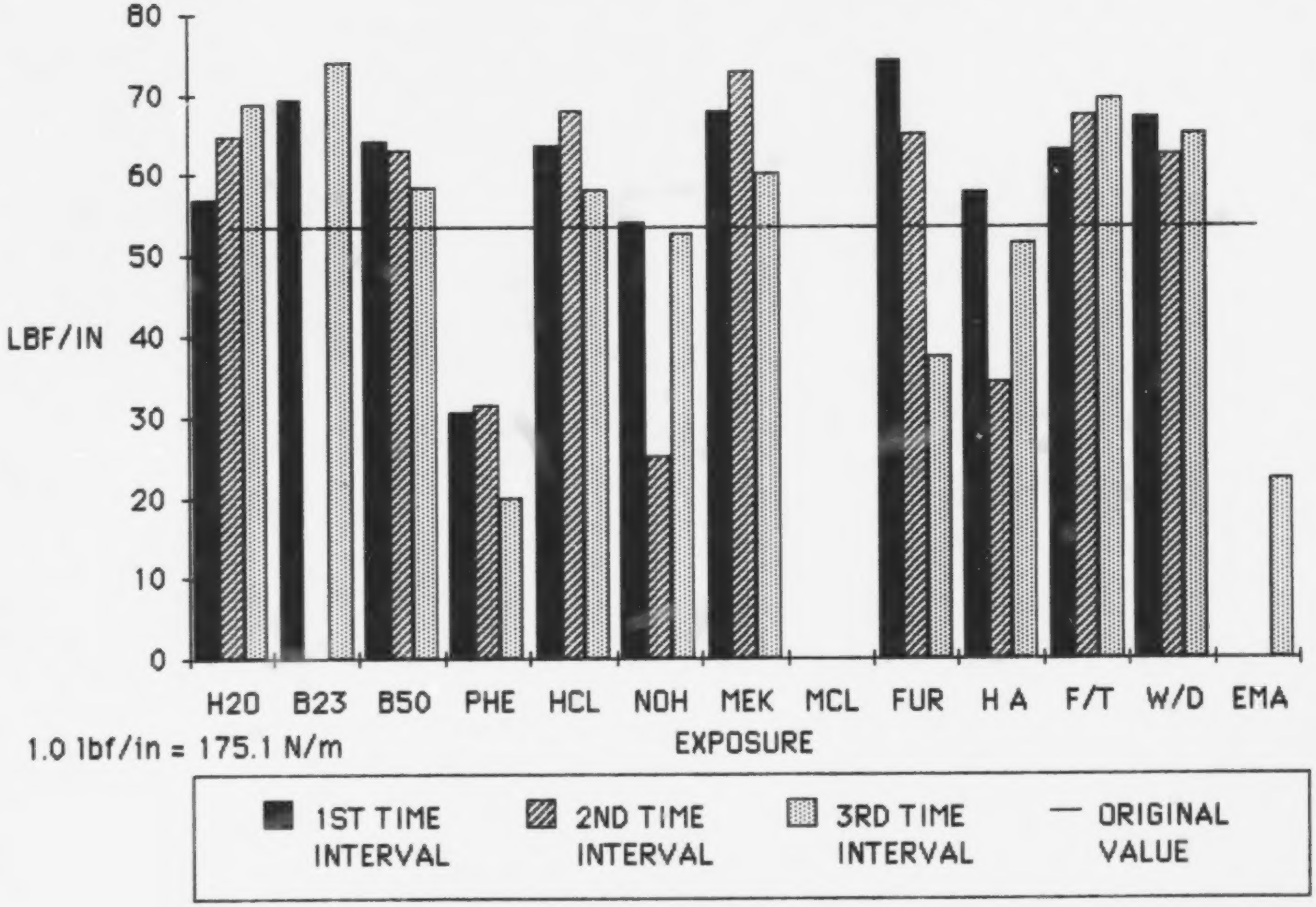


Figure 71. SEAM SHEAR STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 22



1.0 lbf/in = 175.1 N/m

Figure 72. SEAM PEEL STRENGTH - BODIED SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 22



1.0 lbf/in = 175.1 N/m

Figure 73. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 23

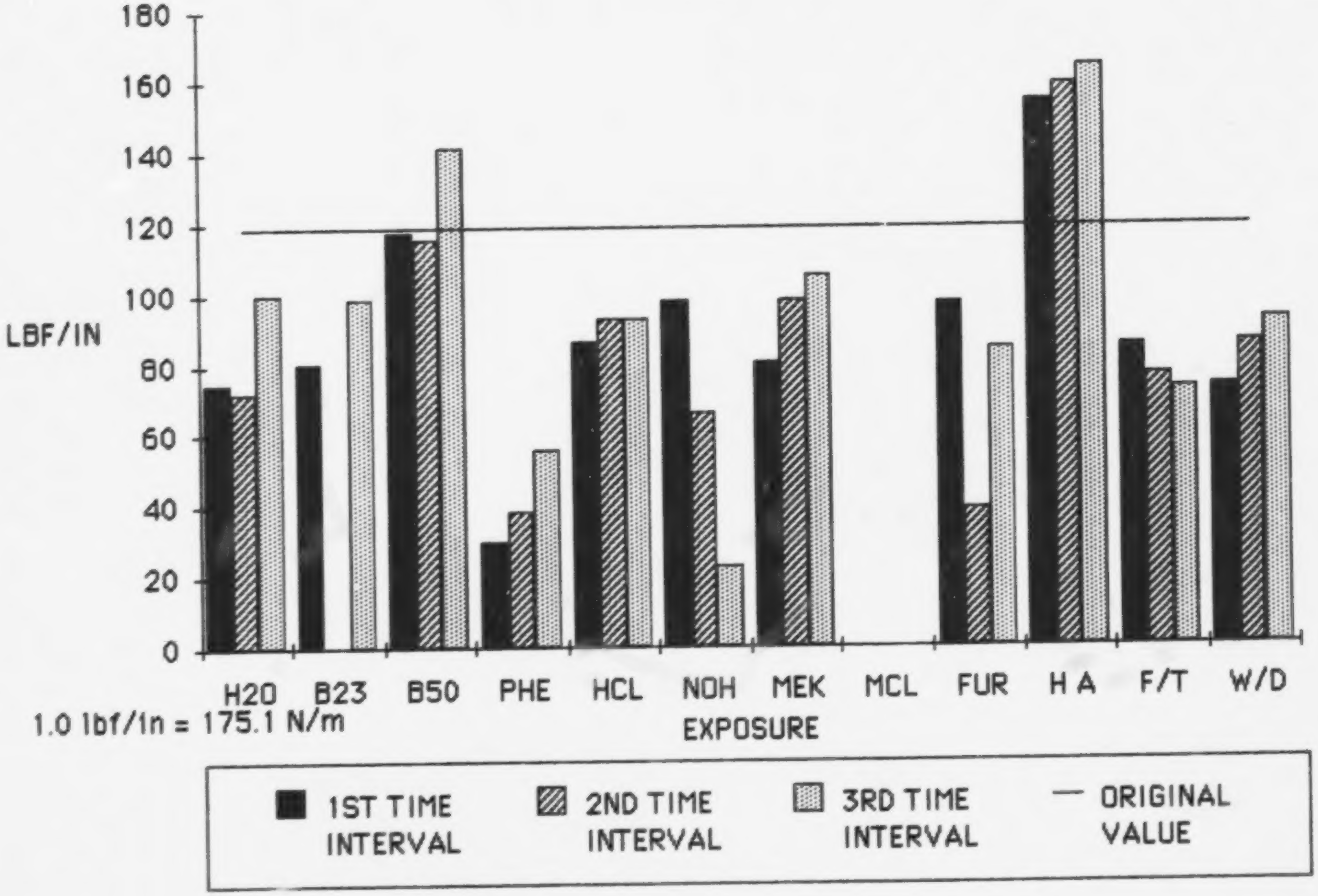
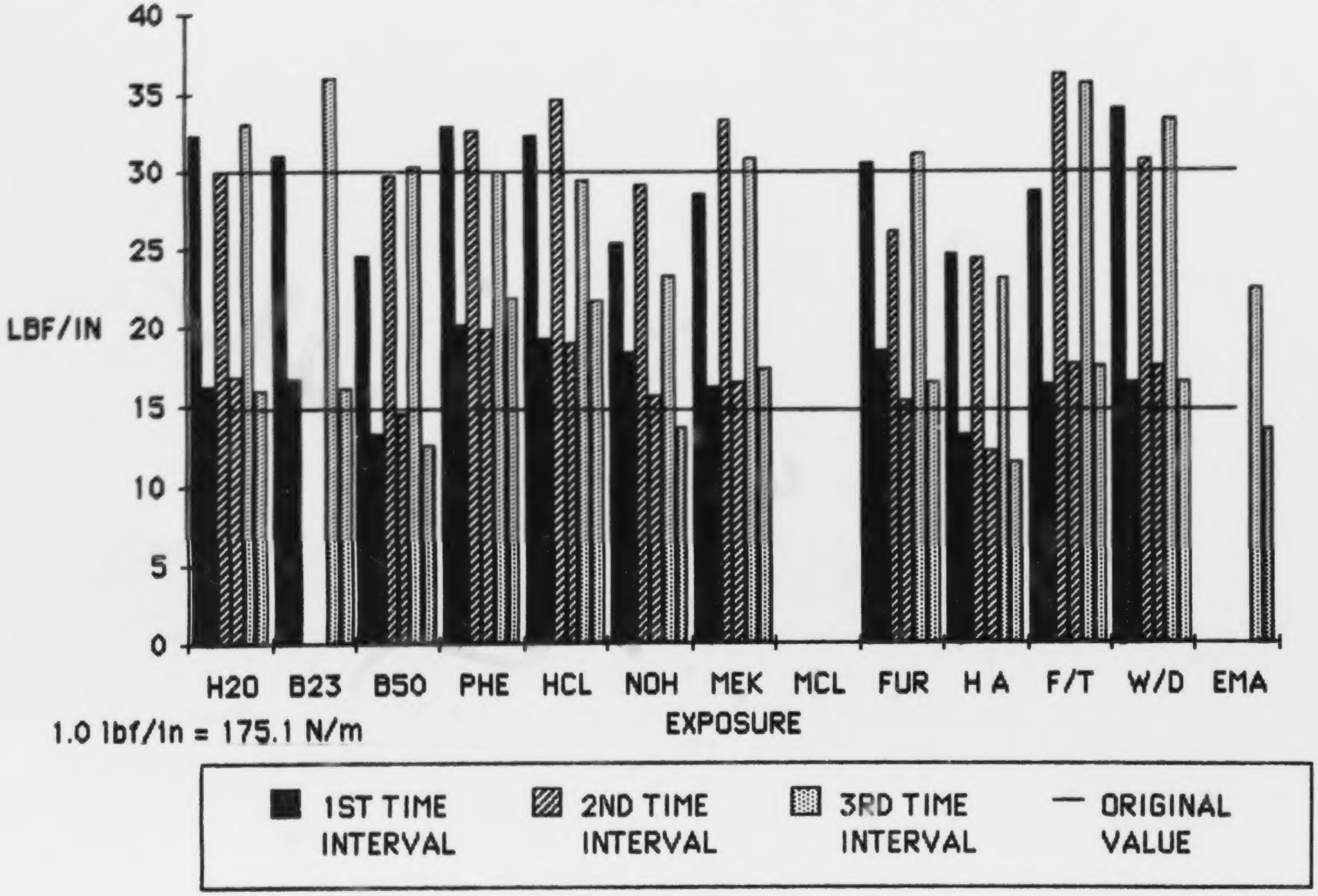
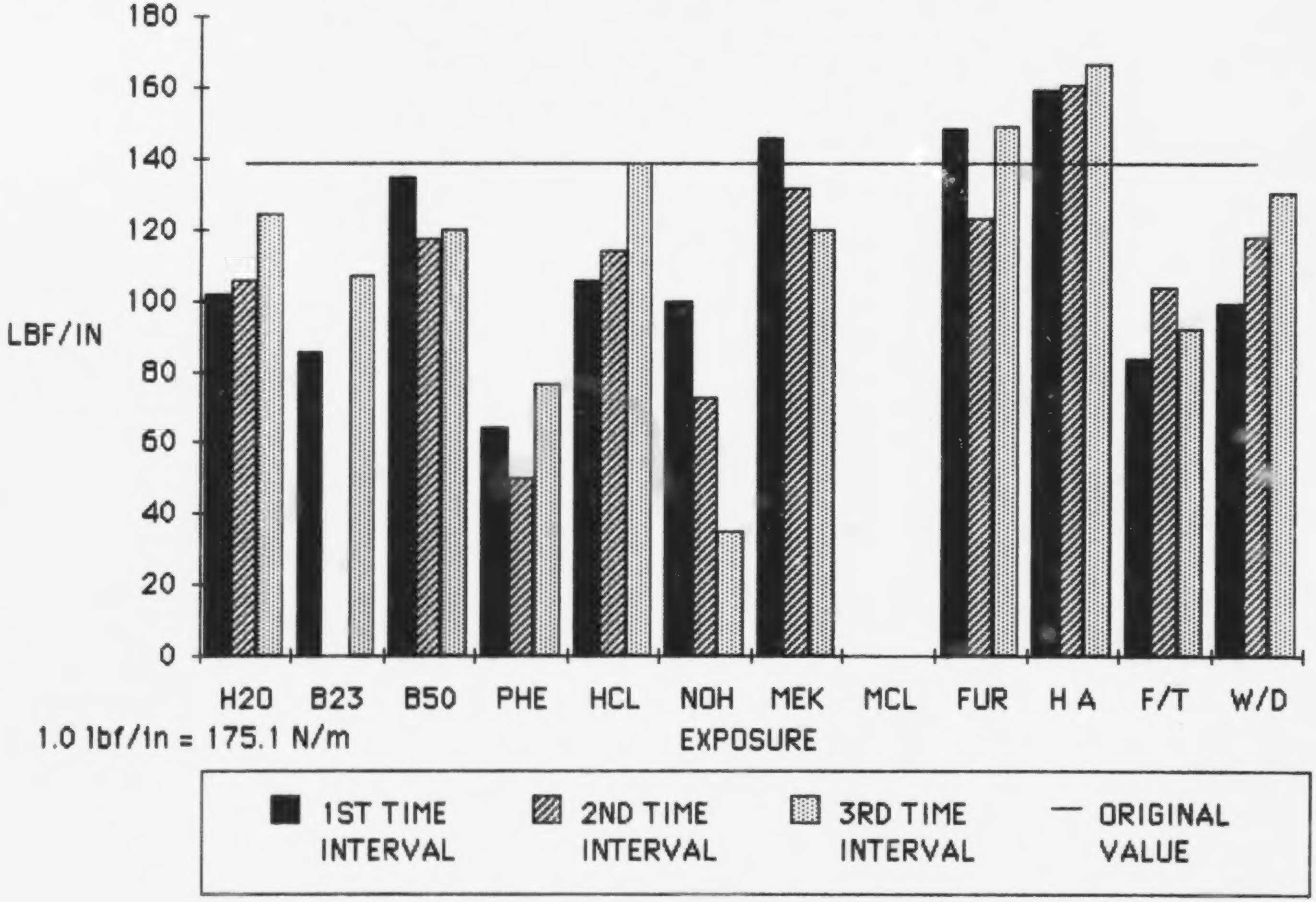


Figure 74. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 23



1.0 lbf/in = 175.1 N/m

Figure 75. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 24



1.0 lbf/in = 175.1 N/m

Figure 76. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 24

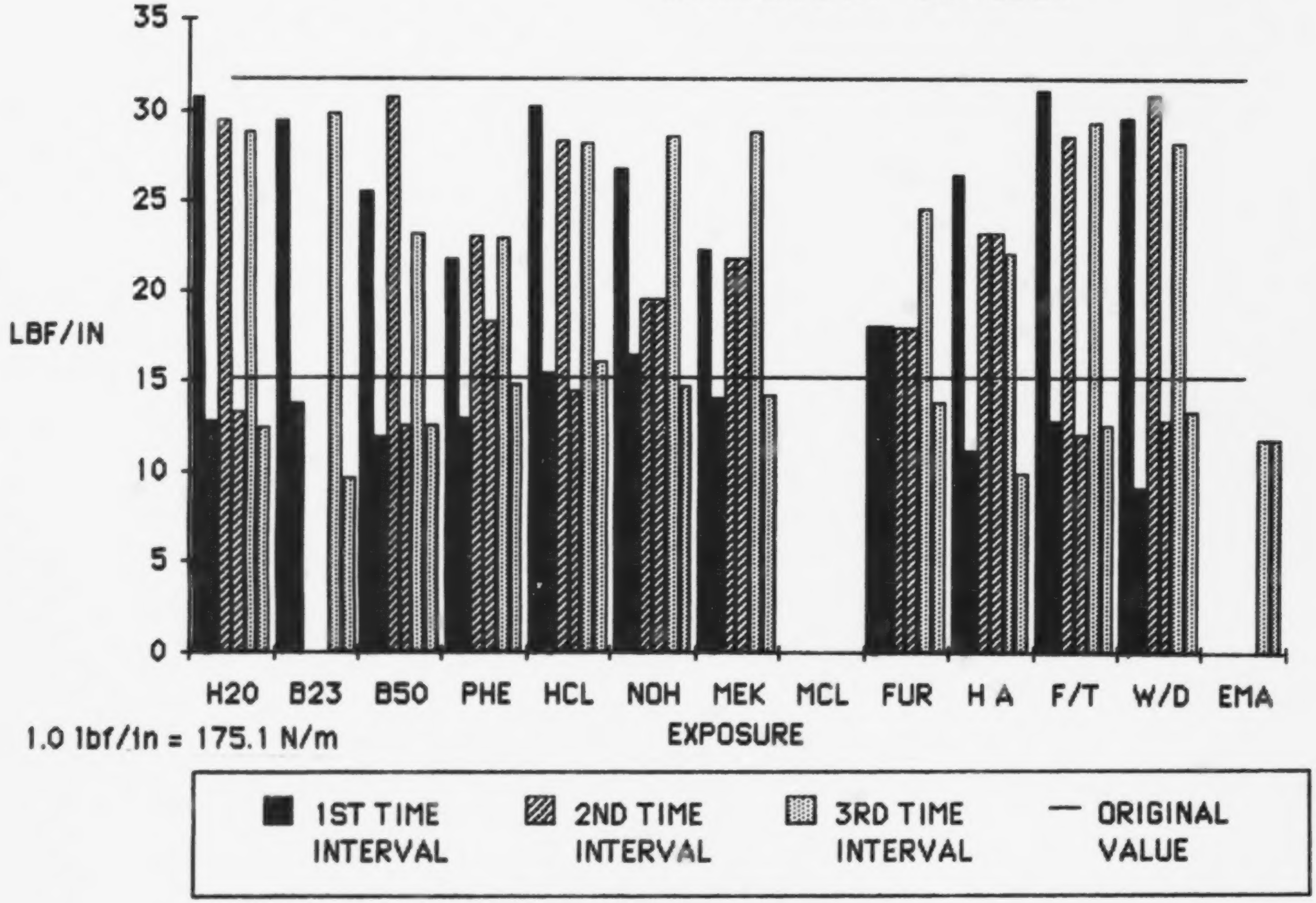


Figure 77. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 25

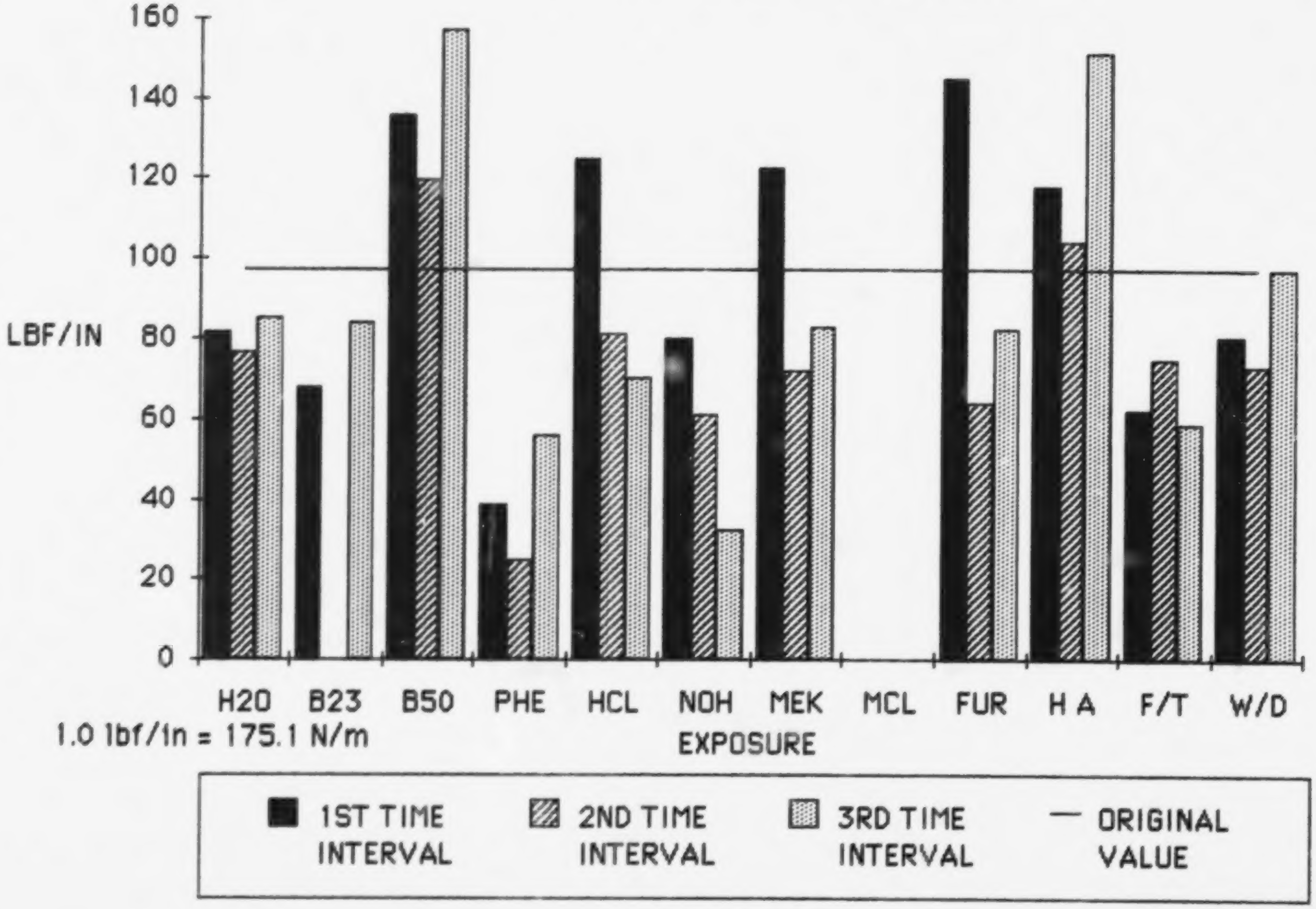
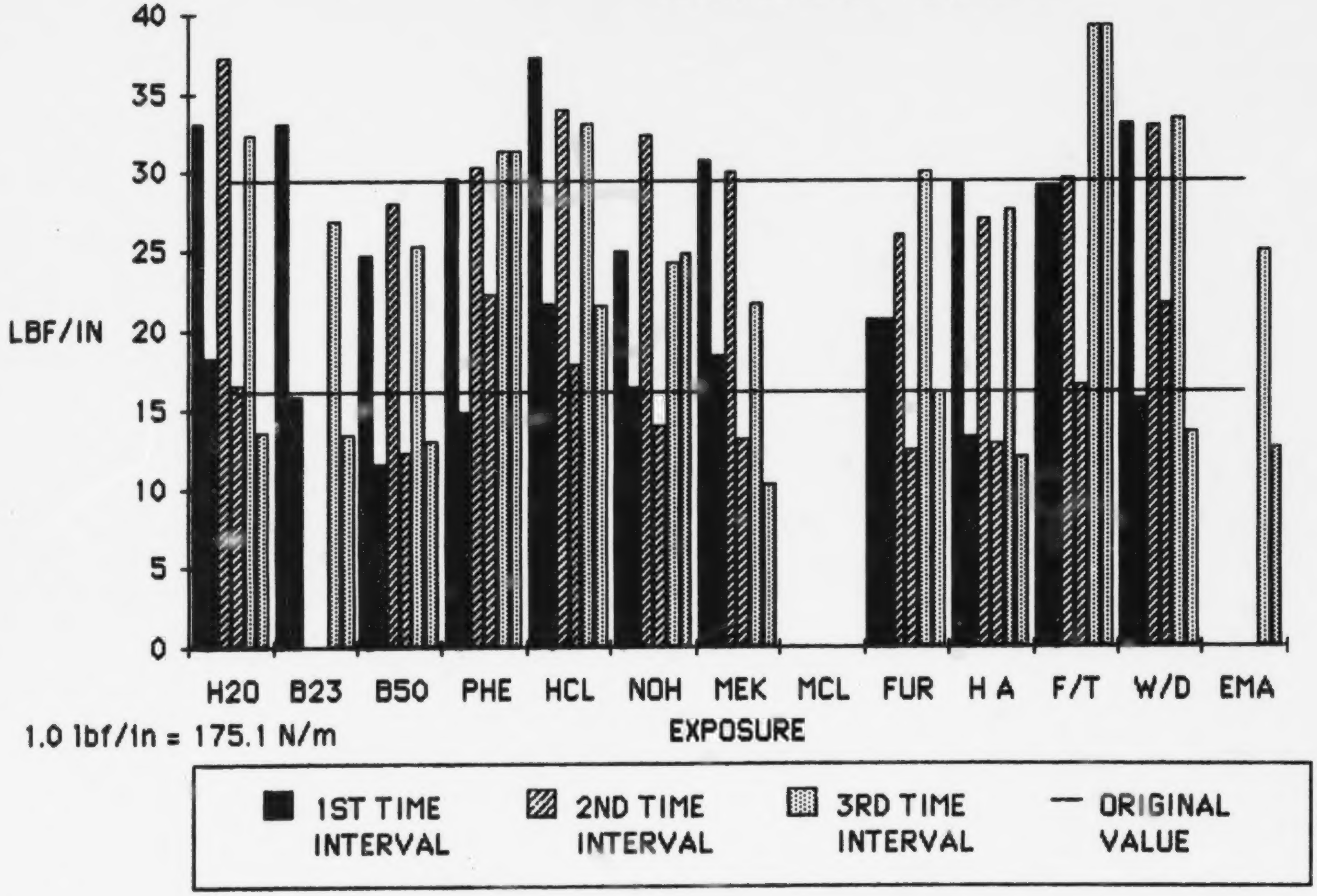
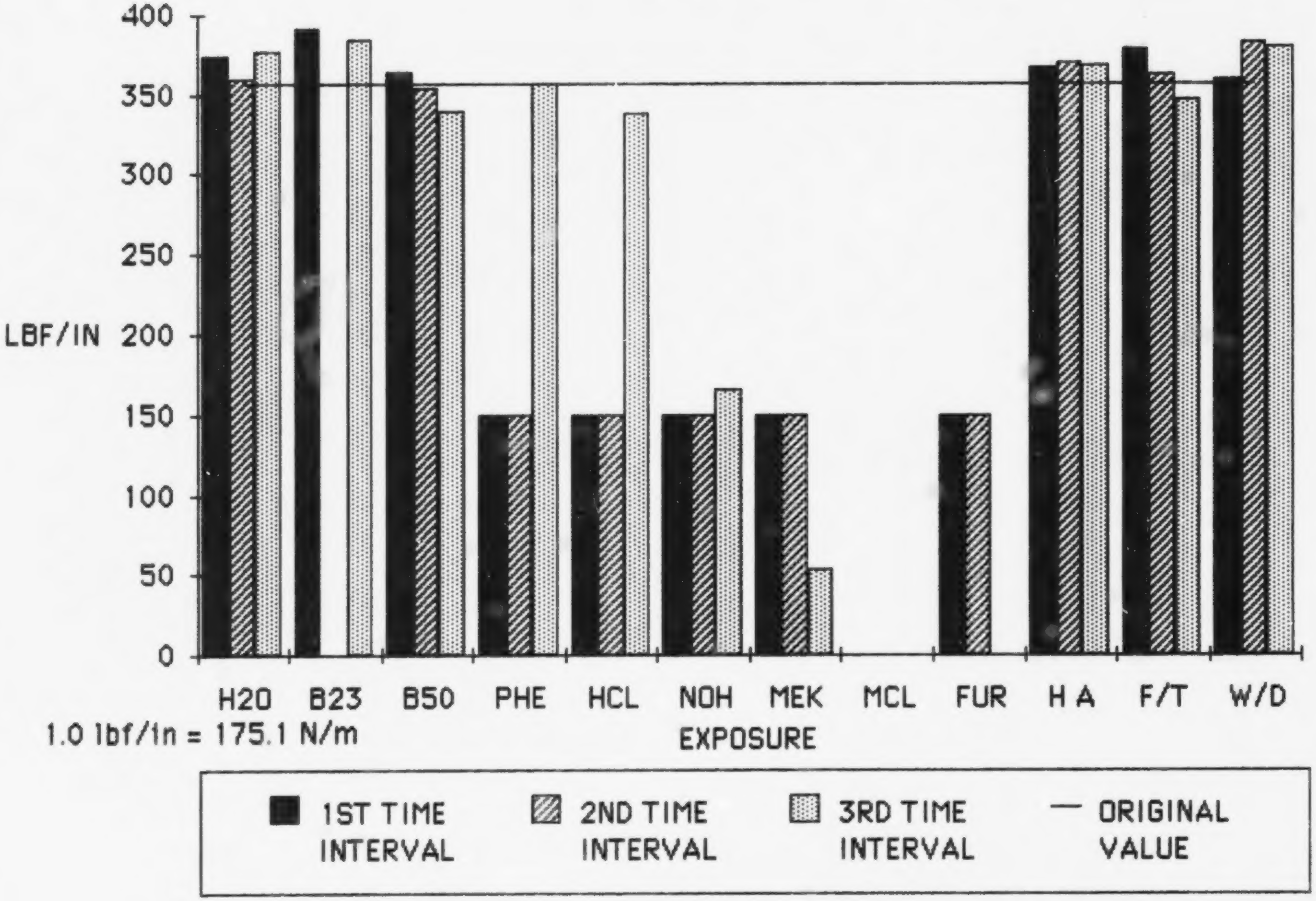


Figure 78. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 36 MIL CSPE (S) - SAMPLE 25



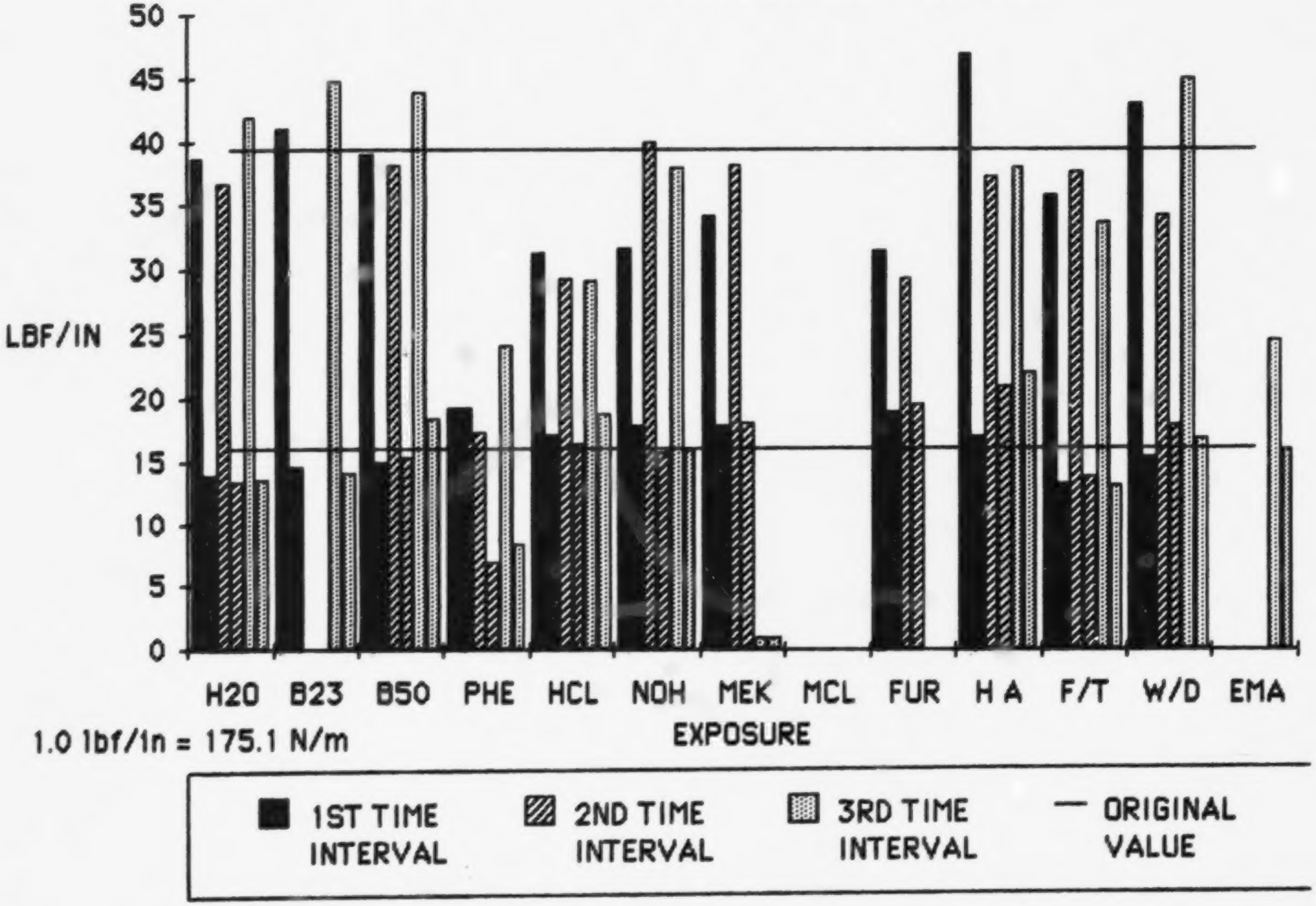
1.0 lbf/in = 175.1 N/m

Figure 79. SEAM SHEAR STRENGTH - THERMAL HOT AIR FIELD SEAM - 38 MIL EIA (S) - SAMPLE 26



1.0 lbf/in = 175.1 N/m

Figure 80. SEAM PEEL STRENGTH - THERMAL HOT AIR FIELD SEAM - 38 MIL EIA (S) - SAMPLE 26



1.0 lbf/in = 175.1 N/m

Figure 81. SEAM SHEAR STRENGTH - GUMTAPE/CEMENT FIELD SEAM - 40 MIL EPDM (S) - SAMPLE 27

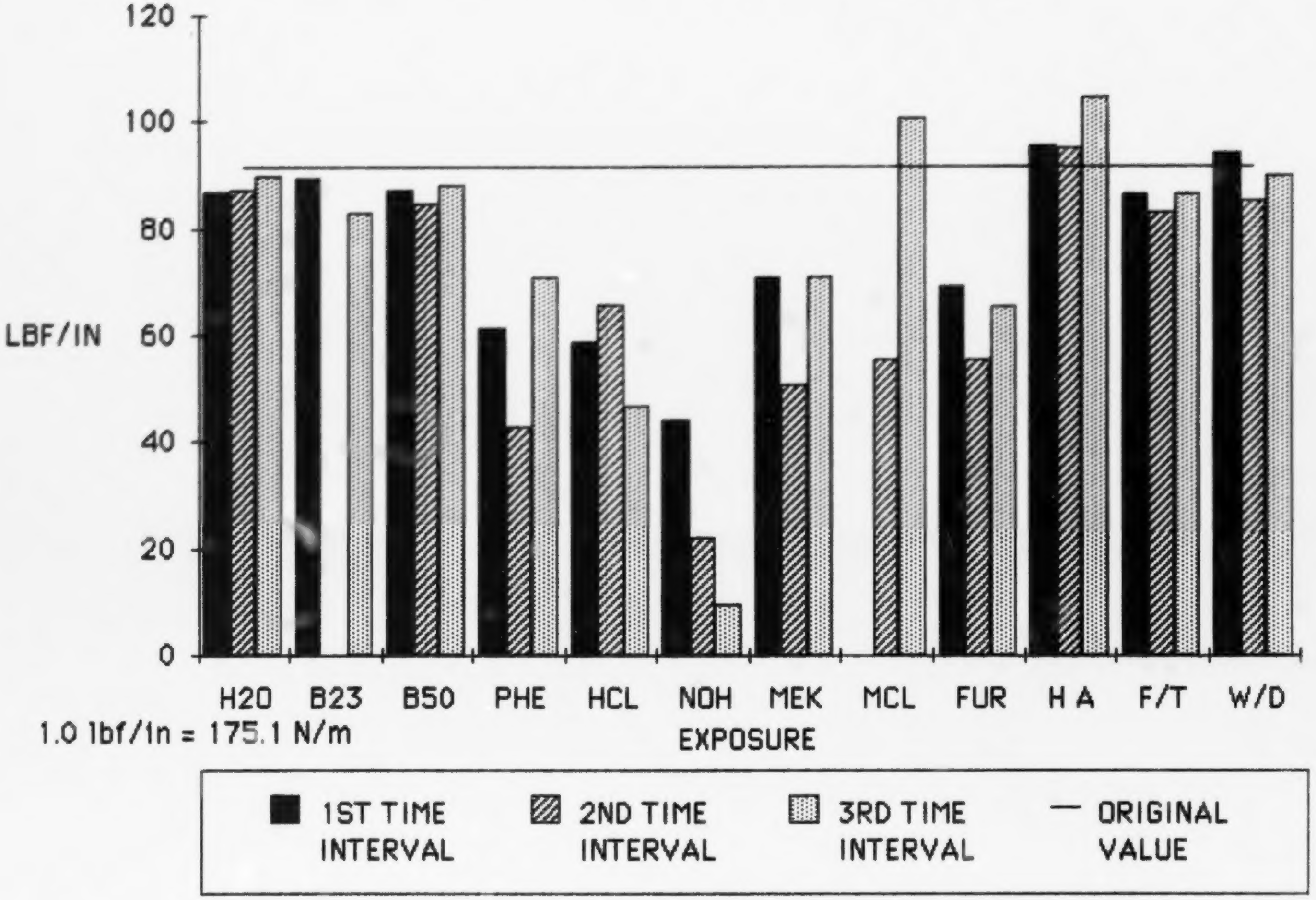


Figure 82. SEAM PEEL STRENGTH - GUMTAPE/CEMENT FIELD SEAM - 40 MIL EPDM (S) - SAMPLE 27

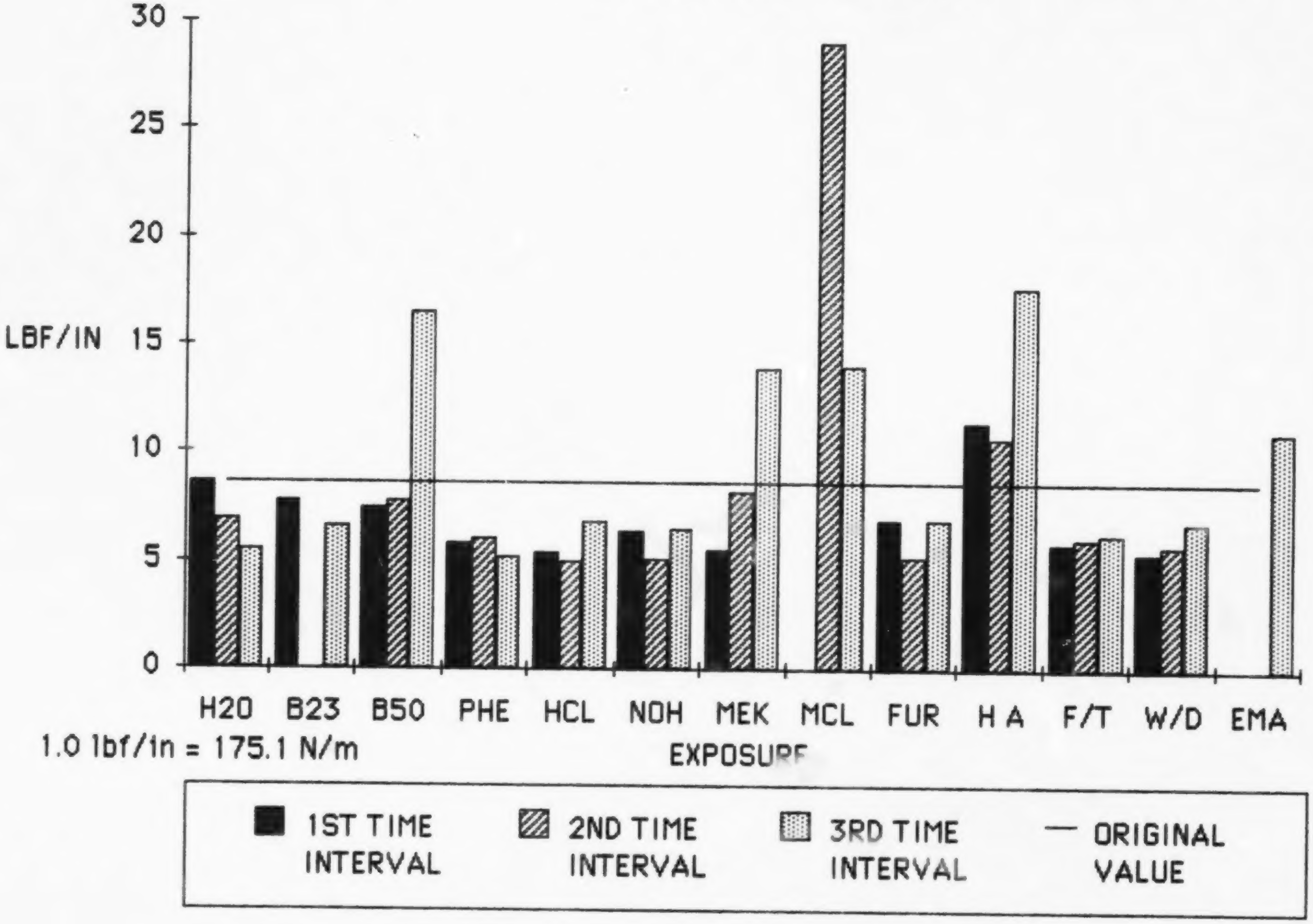


Figure 83. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL CPE (U) - SAMPLE 28

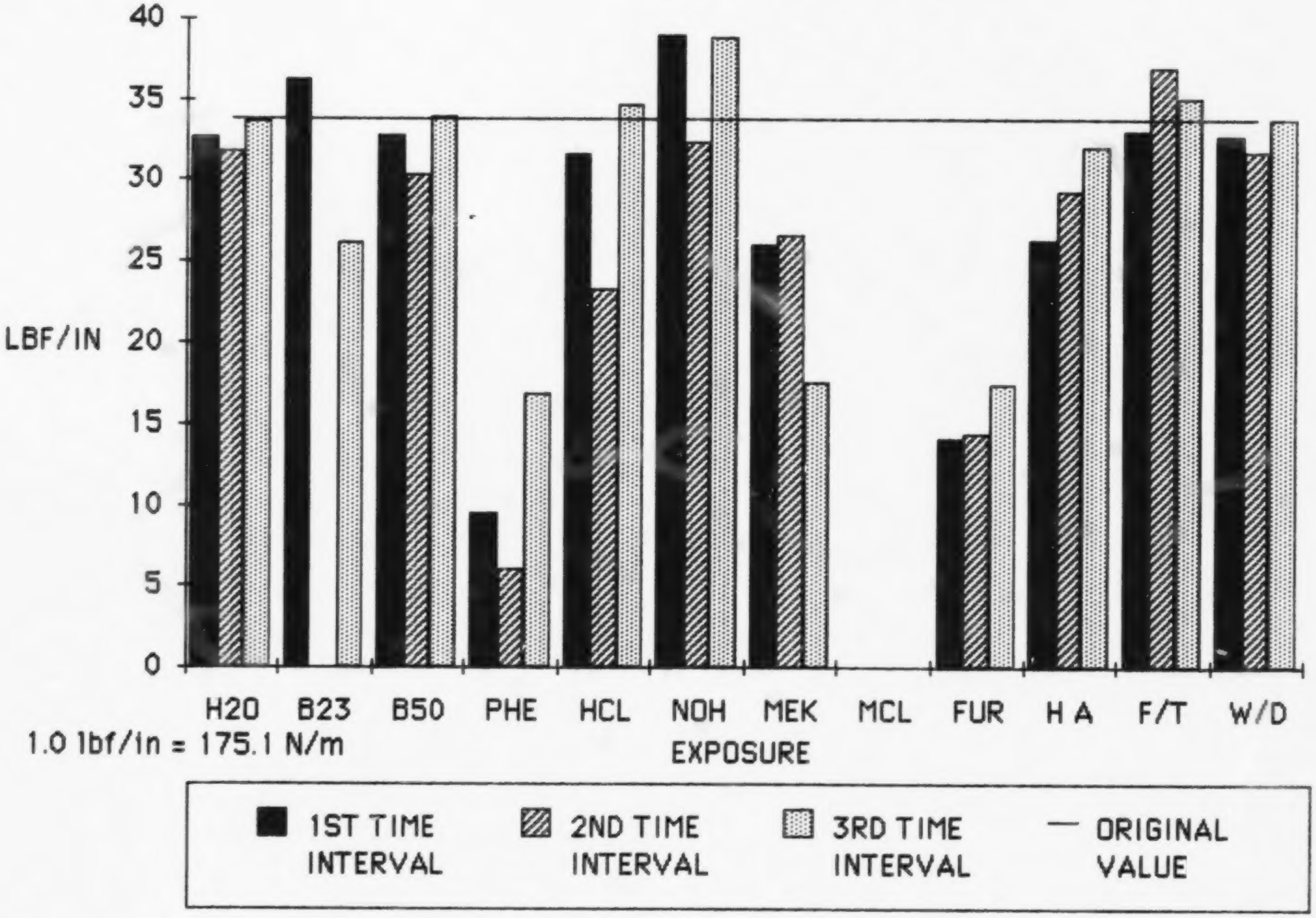


Figure 84. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL CPE (U) - SAMPLE 28

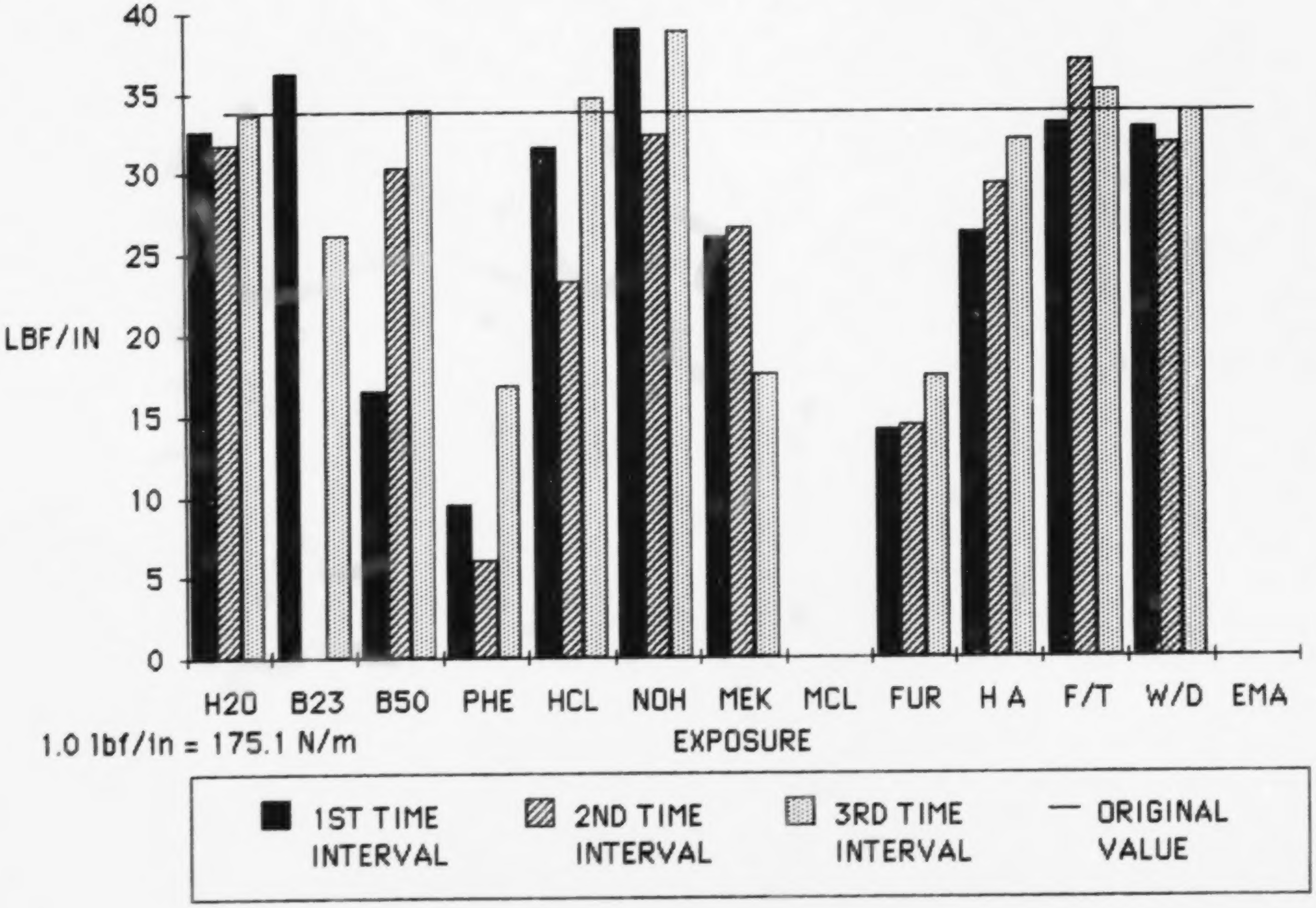


Figure 85. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL CPE (U) - SAMPLE 29

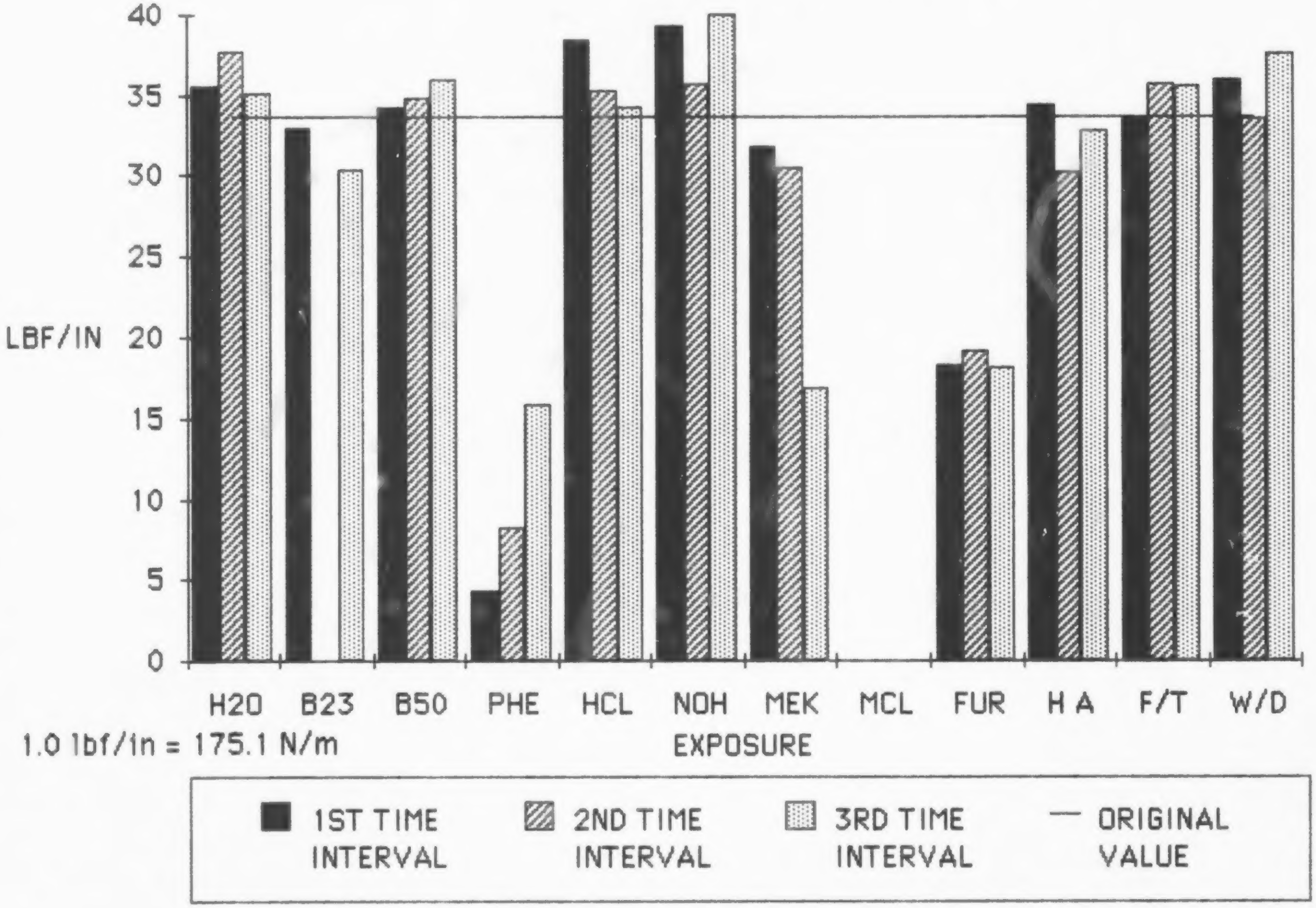


Figure 86. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL CPE (U) - SAMPLE 29

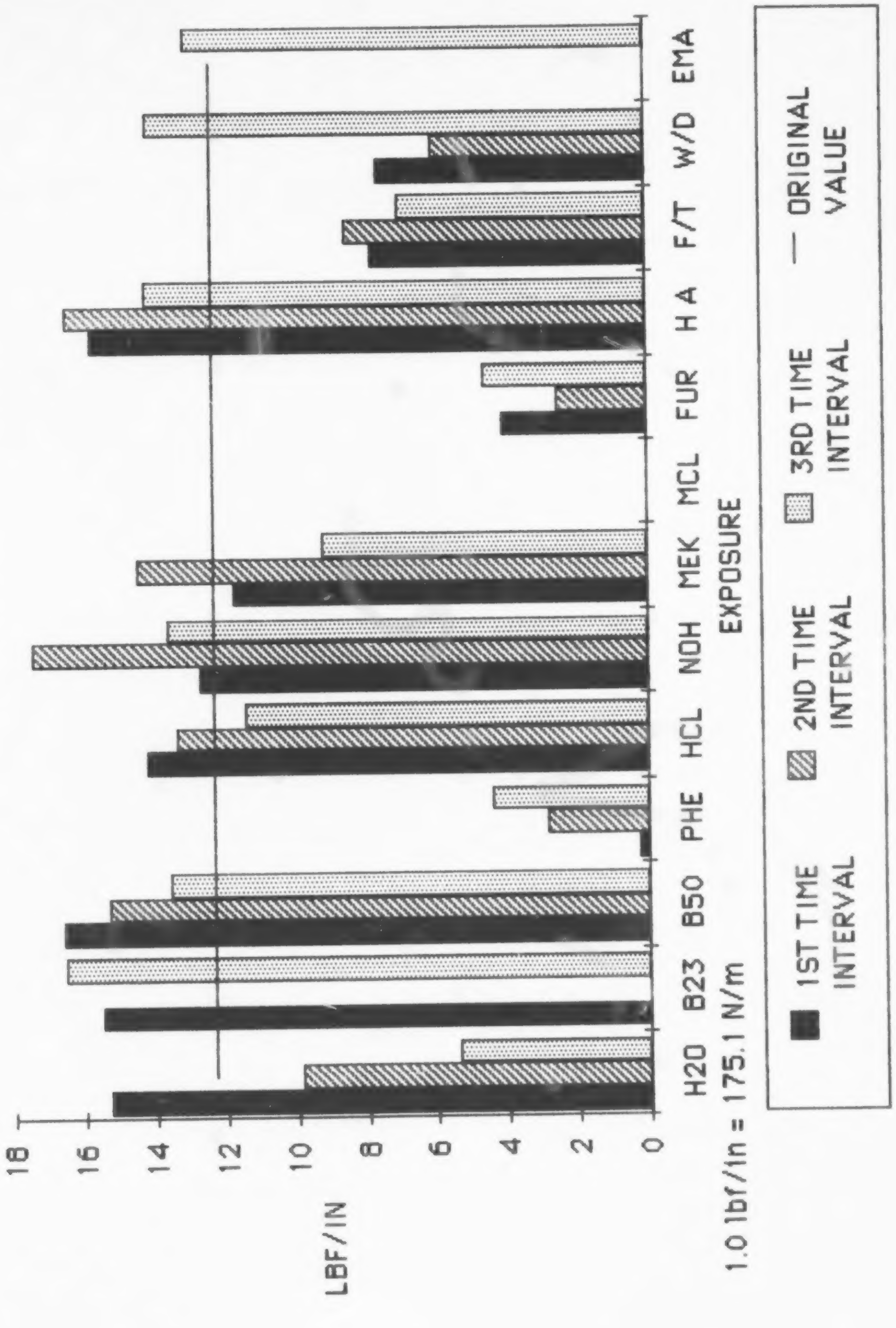
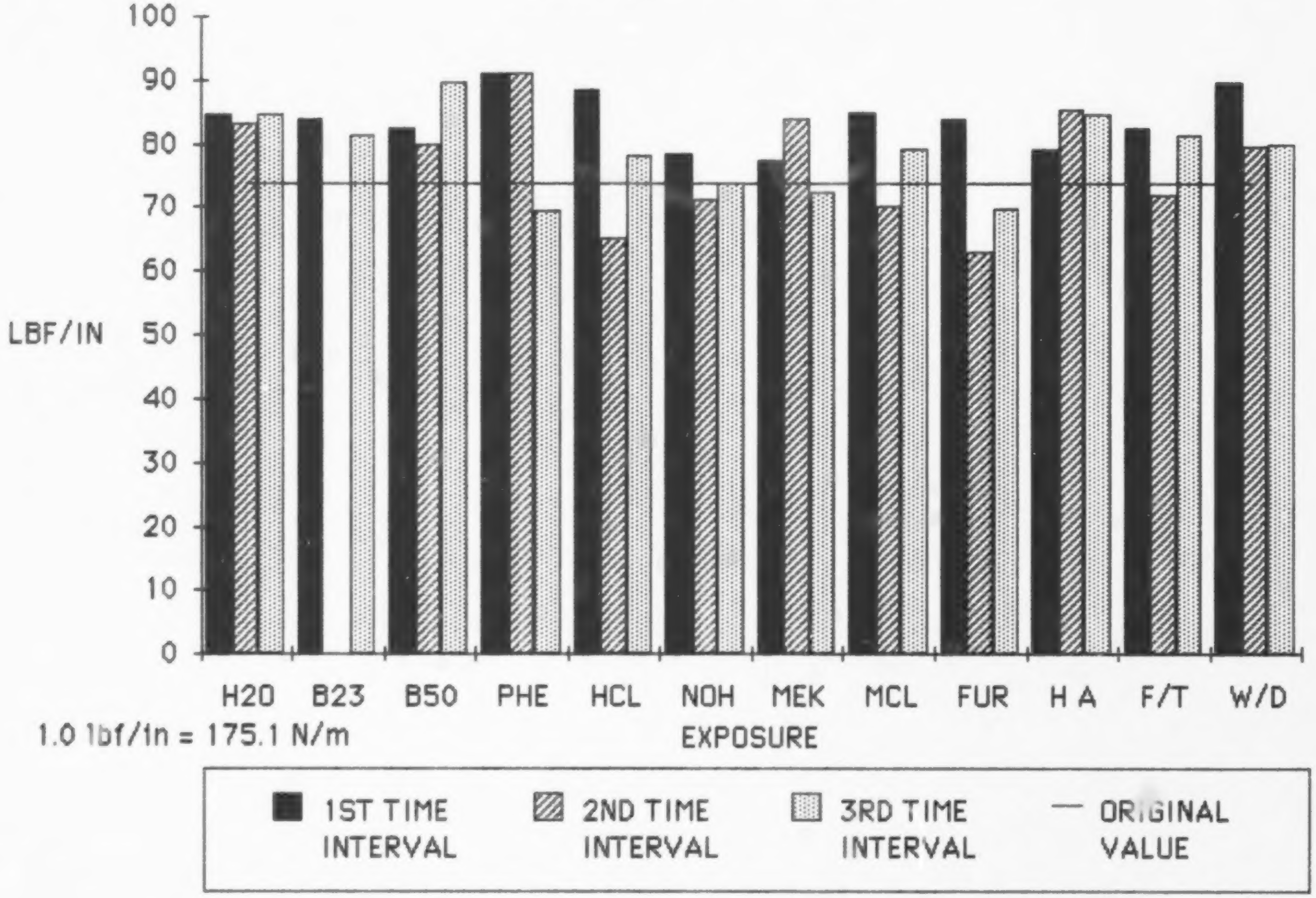


Figure 87. SEAM SHEAR STRENGTH - EXTRUSION FILLET WELD FIELD SEAM - 30 MIL HDPE (U) - SAMPLE 30



1.0 lbf/in = 175.1 N/m

Figure 88. SEAM PEEL STRENGTH - EXTRUSION FILLET WELD FIELD SEAM - 30 MIL HDPE (U) - SAMPLE 30

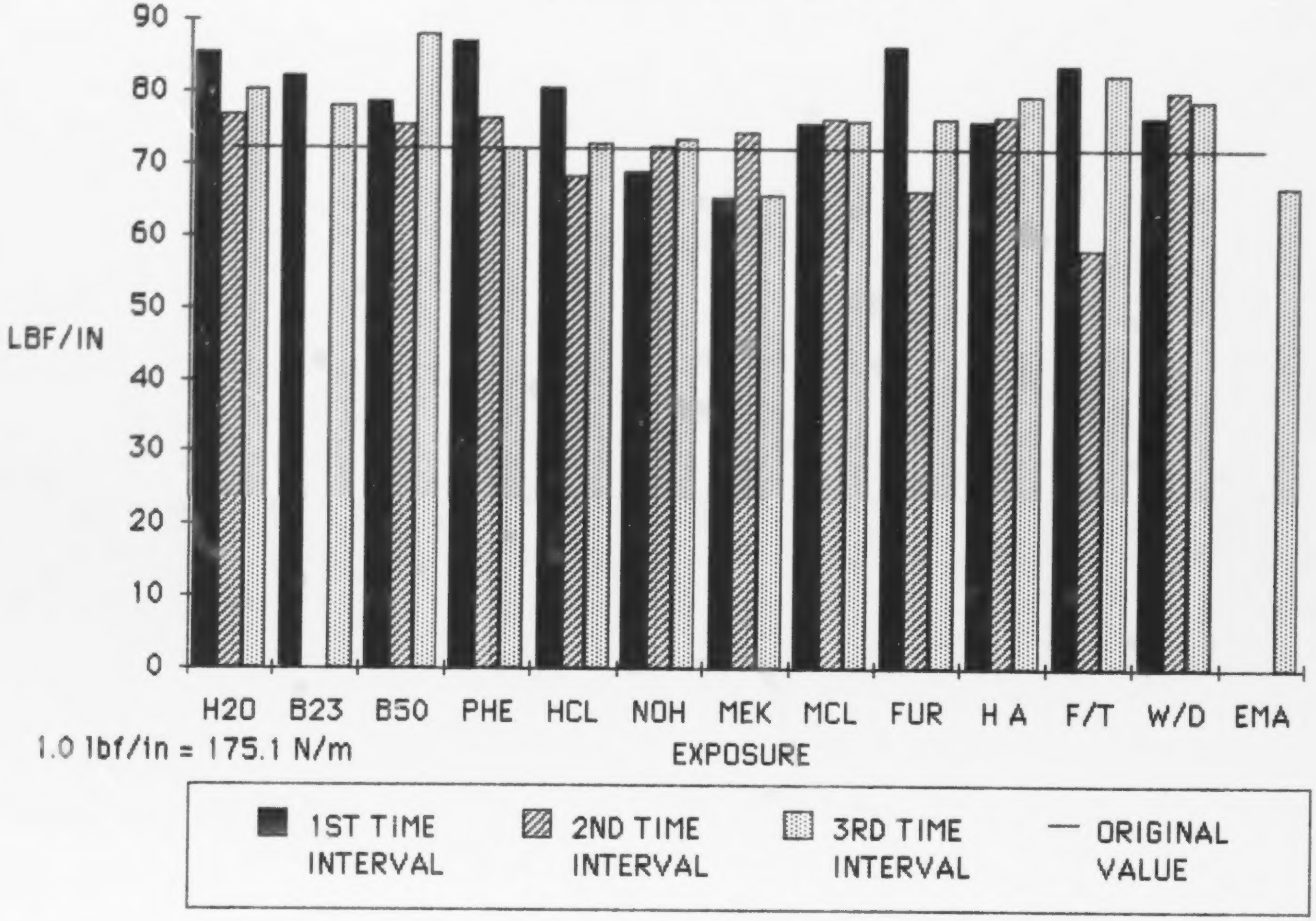


Figure 89. SEAM SHEAR STRENGTH - EXTRUSION FILLET WELD FIELD SEAM - 80 MIL HDPE (U) - SAMPLE 31

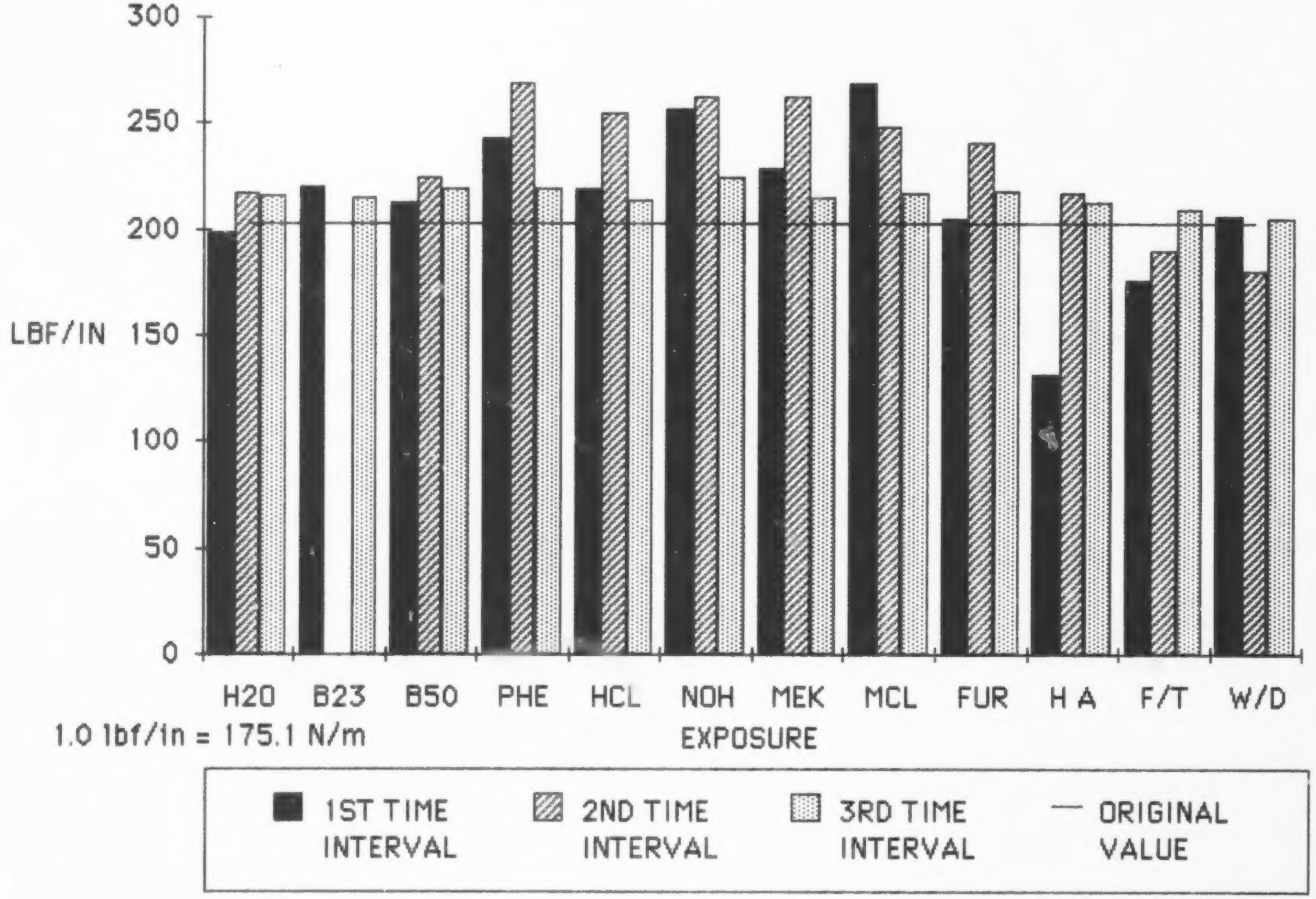
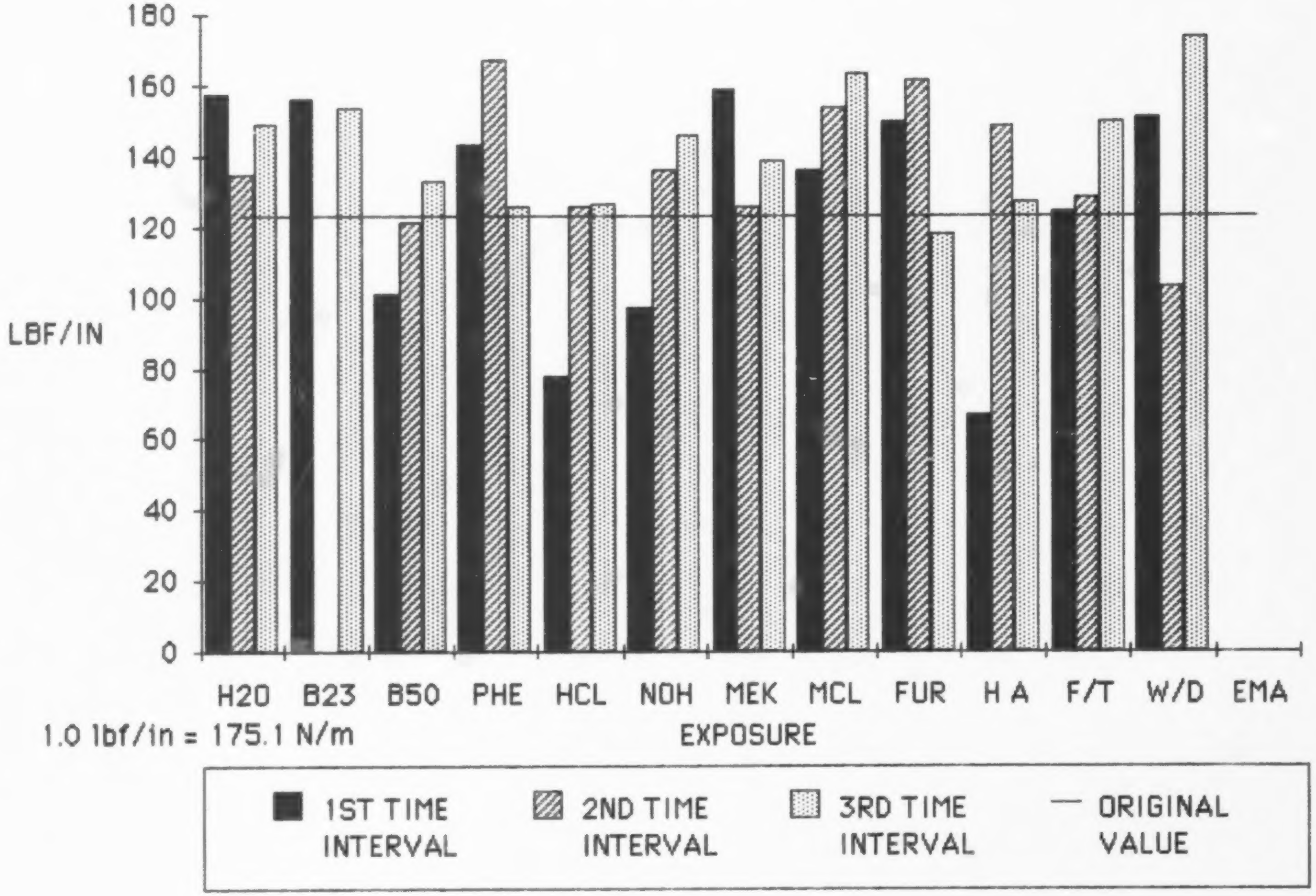


Figure 90. SEAM PEEL STRENGTH - EXTRUSION FILLET WELD FIELD SEAM - 80 MIL HDPE (U) - SAMPLE 31



1.0 lbf/in = 175.1 N/m

Figure 91. SEAM SHEAR STRENGTH - EXTRUSION LAP WELD FIELD SEAM - 80 MIL HDPE (U) - SAMPLE 32

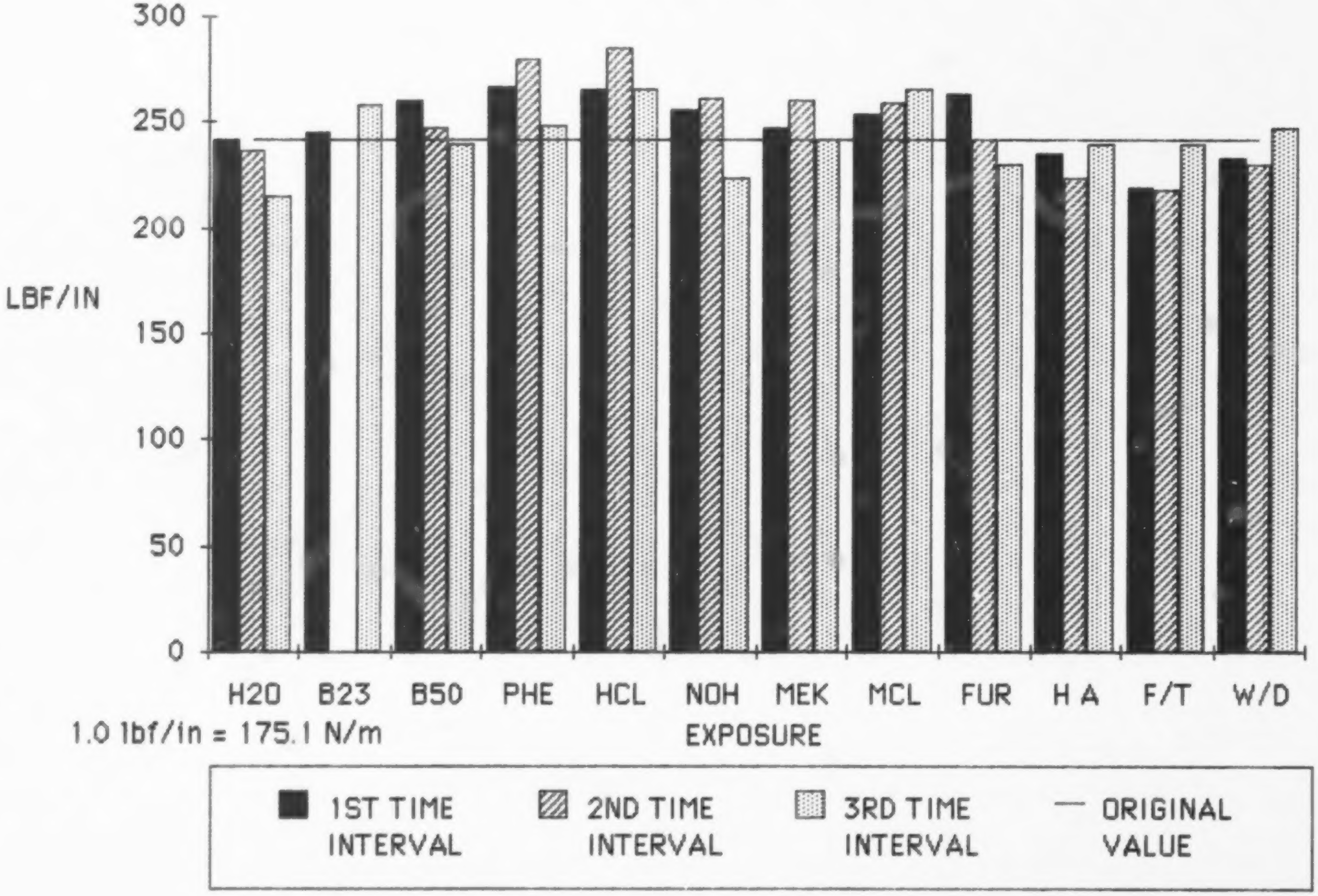


Figure 92. SEAM PEEL STRENGTH - EXTRUSION LAP WELD FIELD SEAM - 80 MIL HDPE (U) - SAMPLE 32

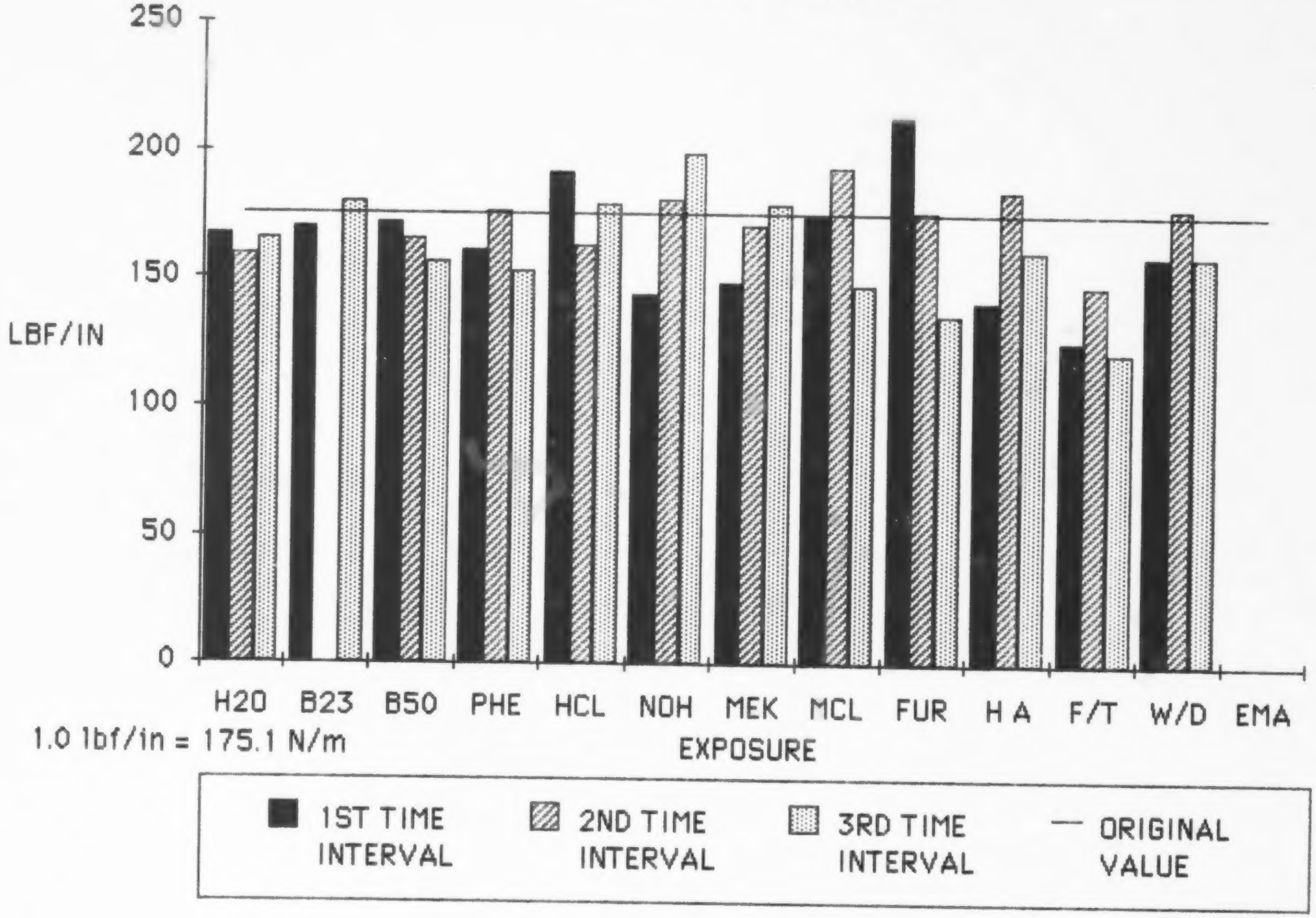
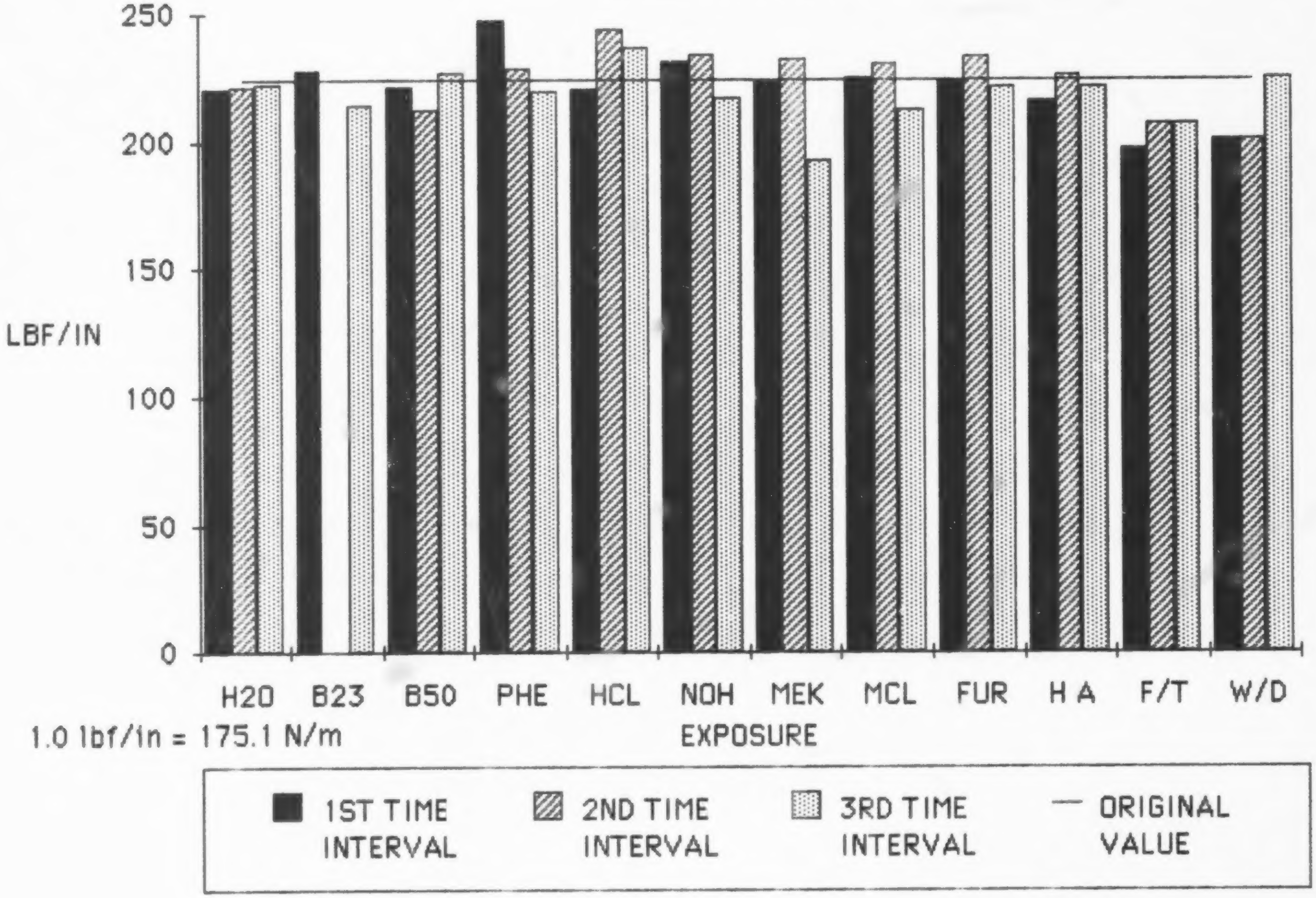
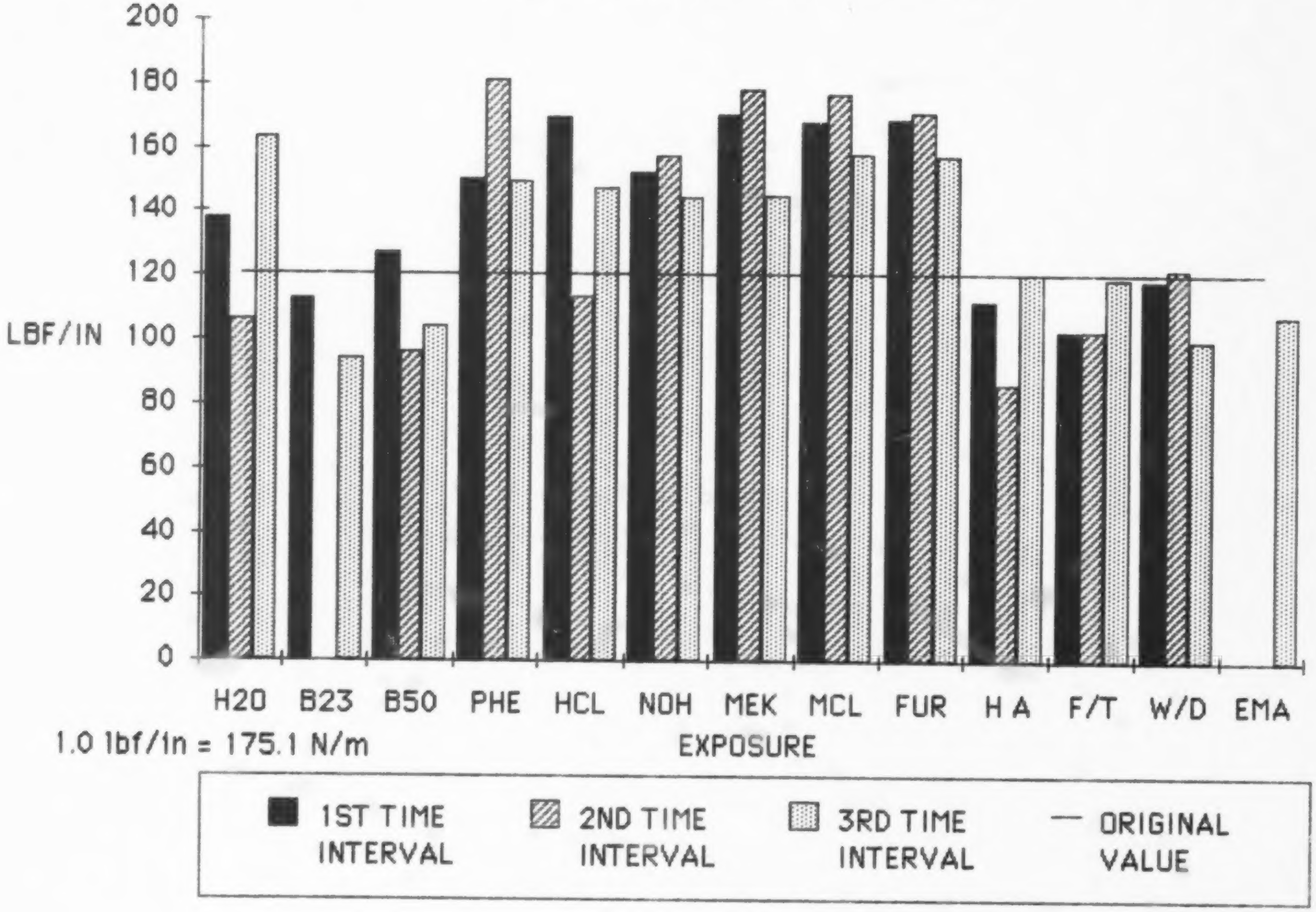


Figure 93. SEAM SHEAR STRENGTH - THERMAL HOT DUAL WEDGE FIELD SEAM - 80 MIL HDPE (U) - SAMPLE 33



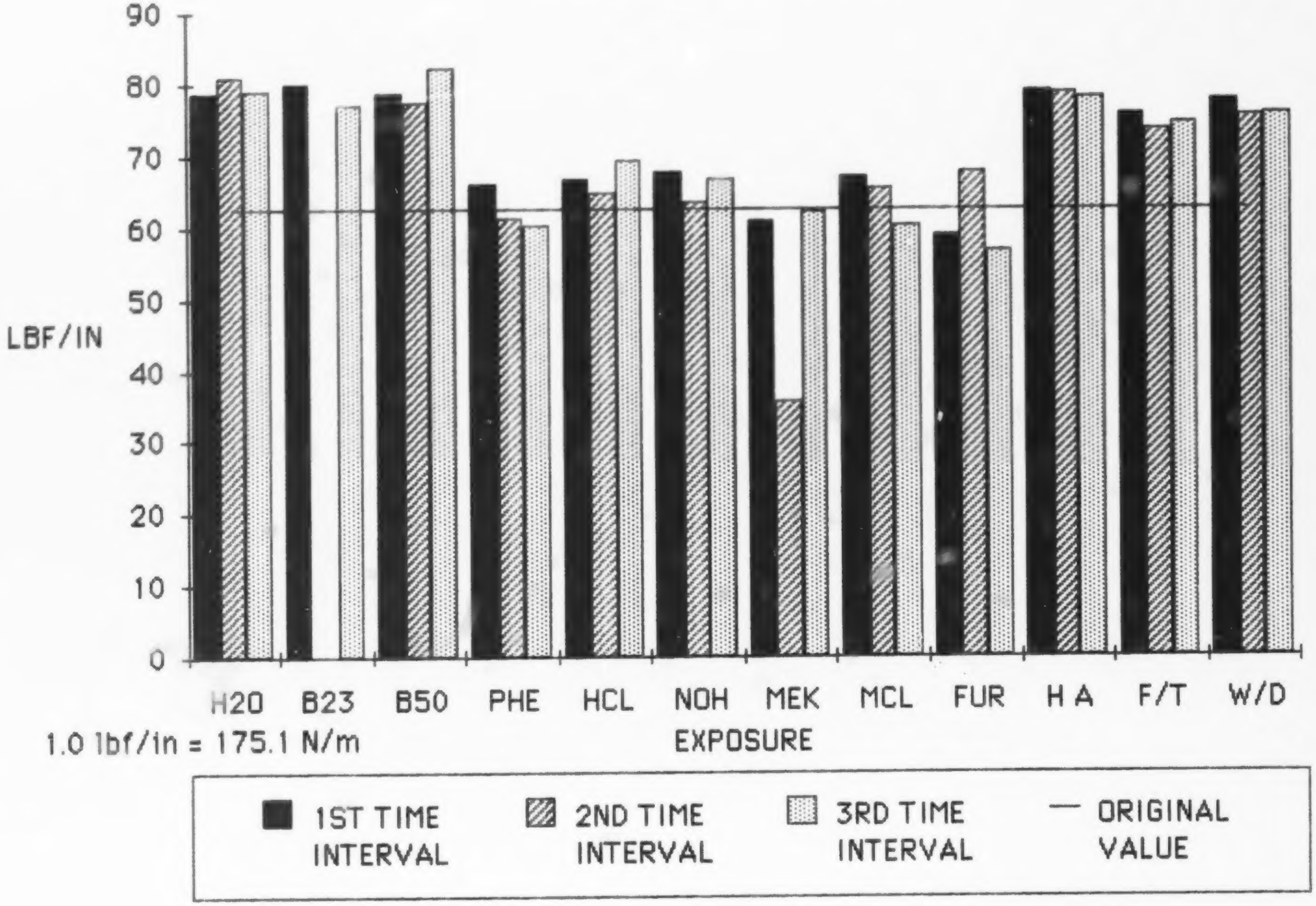
1.0 lbf/in = 175.1 N/m

Figure 94. SEAM PEEL STRENGTH - THERMAL HOT DUAL WEDGE FIELD SEAM - 80 MIL HDPE (U) - SAMPLE 33



1.0 lbf/in = 175.1 N/m

Figure 95. SEAM SHEAR STRENGTH - THERMAL HOT WEDGE FIELD SEAM - 30 MIL LLDPE (U) - SAMPLE 34



1.0 lbf/in = 175.1 N/m

Figure 96. SEAM PEEL STRENGTH - THERMAL HOT WEDGE FIELD SEAM - 80 MIL LLDPE (U) - SAMPLE 34

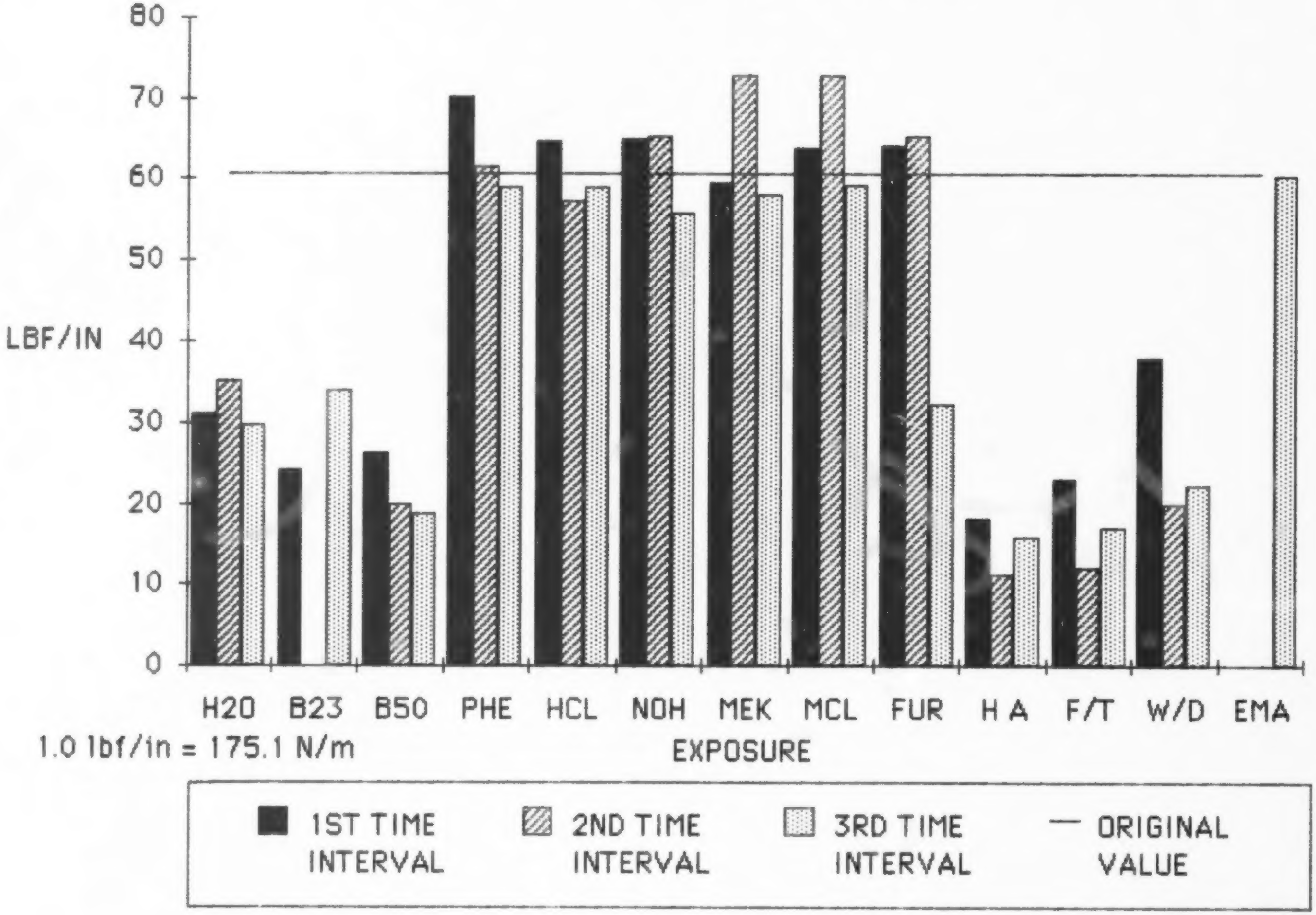


Figure 97. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL PVC (U) - SAMPLE 35

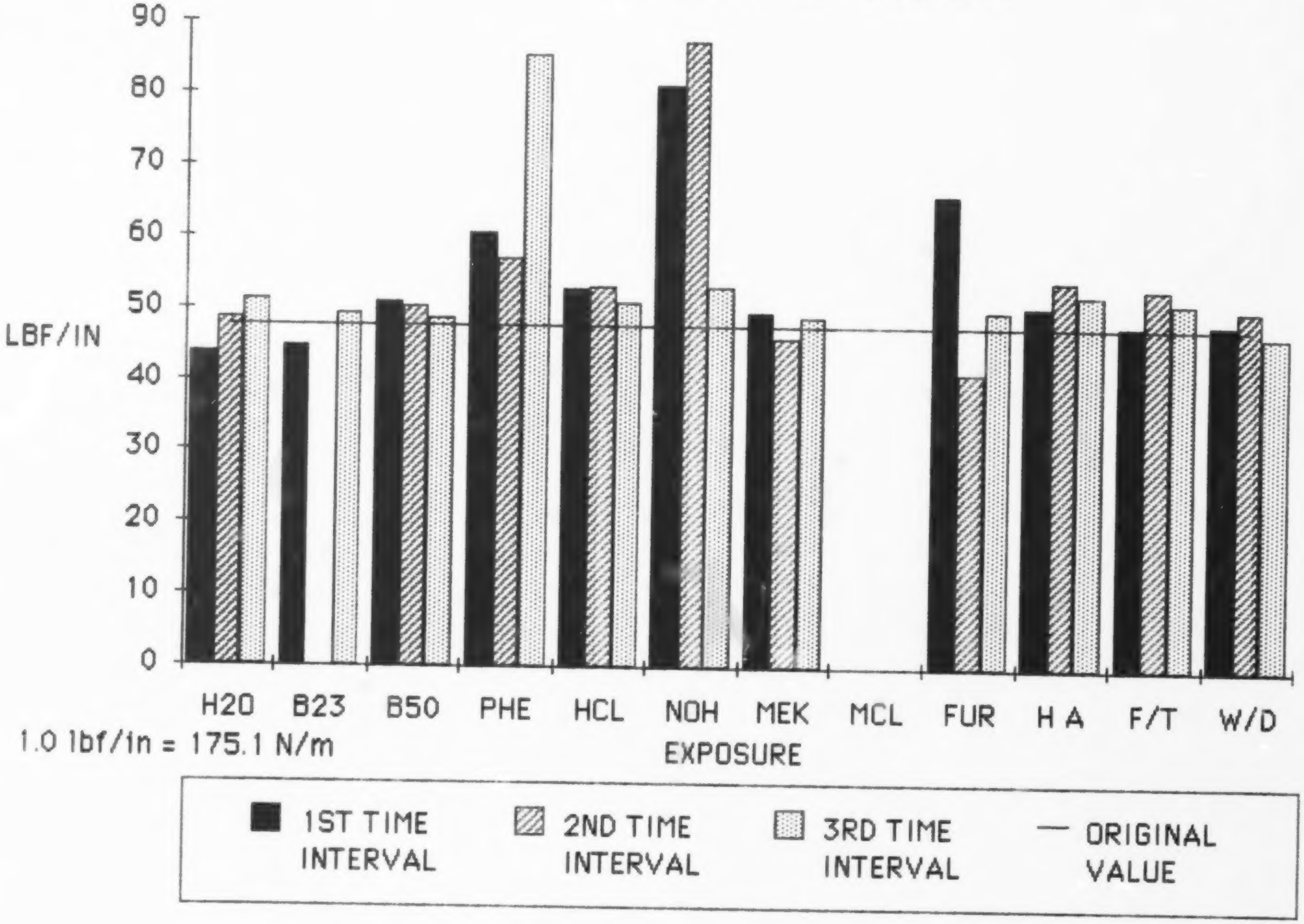
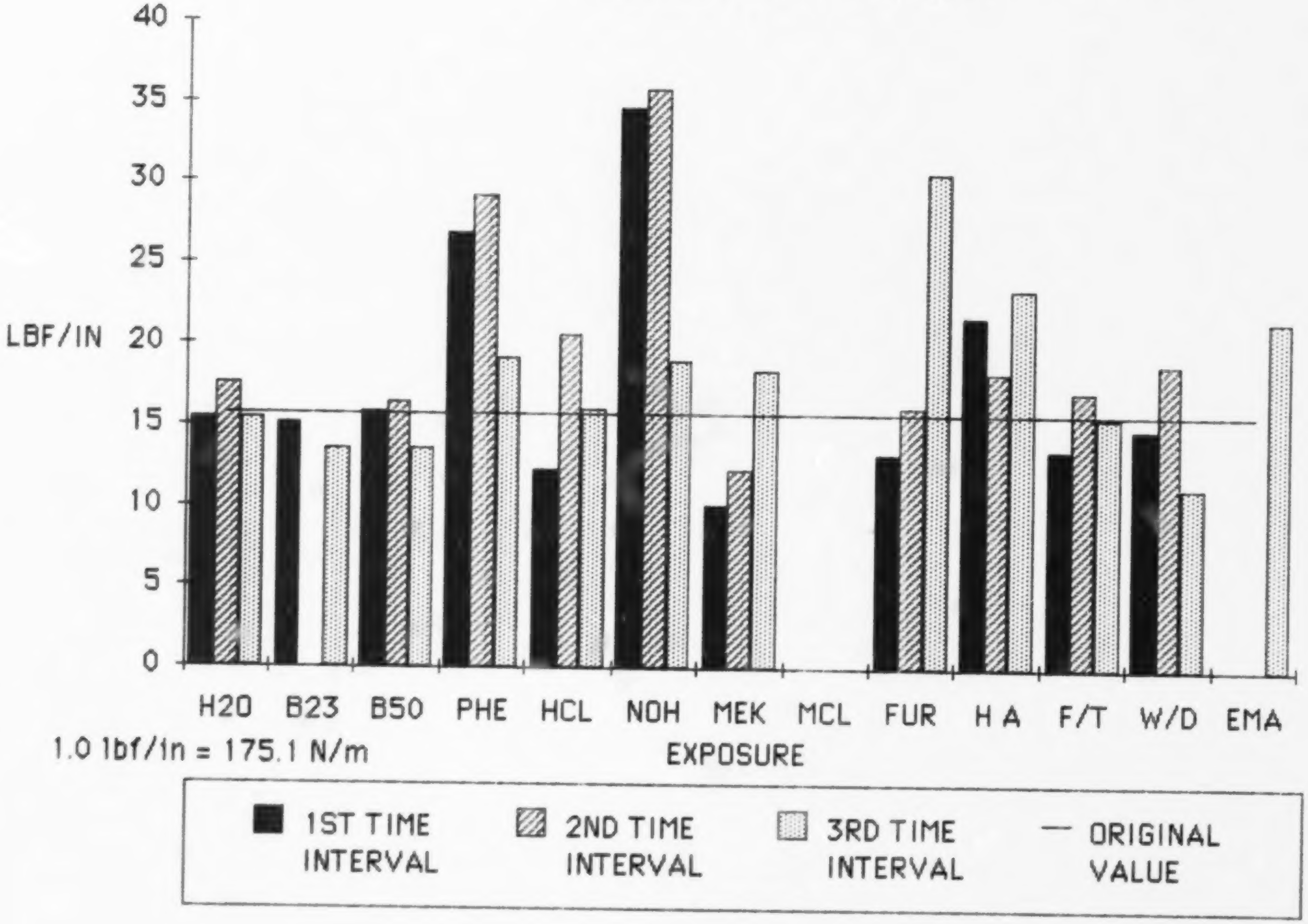
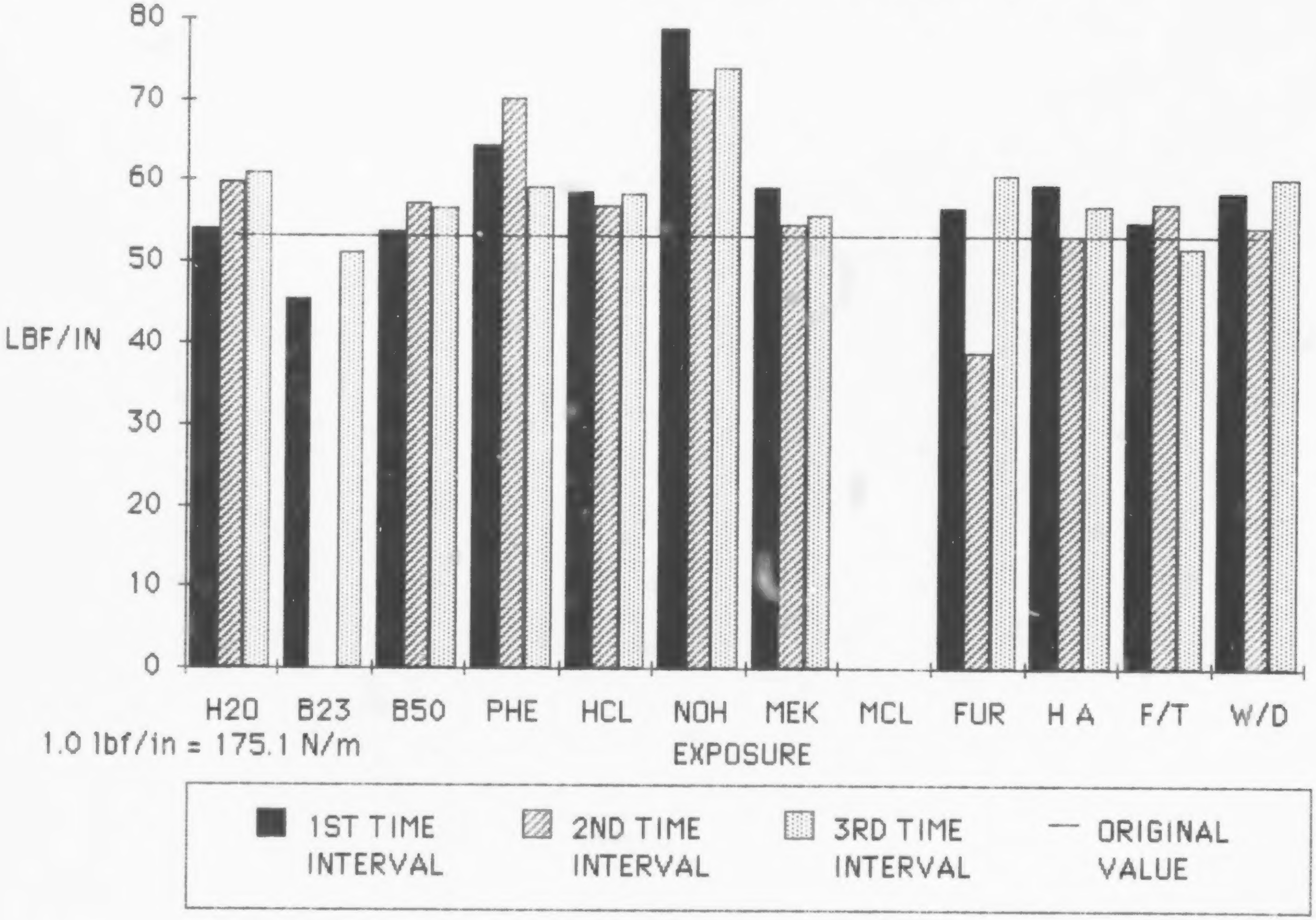


Figure 98. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL PVC (U) - SAMPLE 35



1.0 lbf/in = 175.1 N/m

Figure 99. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL PVC (U) - SAMPLE 36



1.0 lbf/in = 175.1 N/m

Figure 100. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL PVC (U) - SAMPLE 36

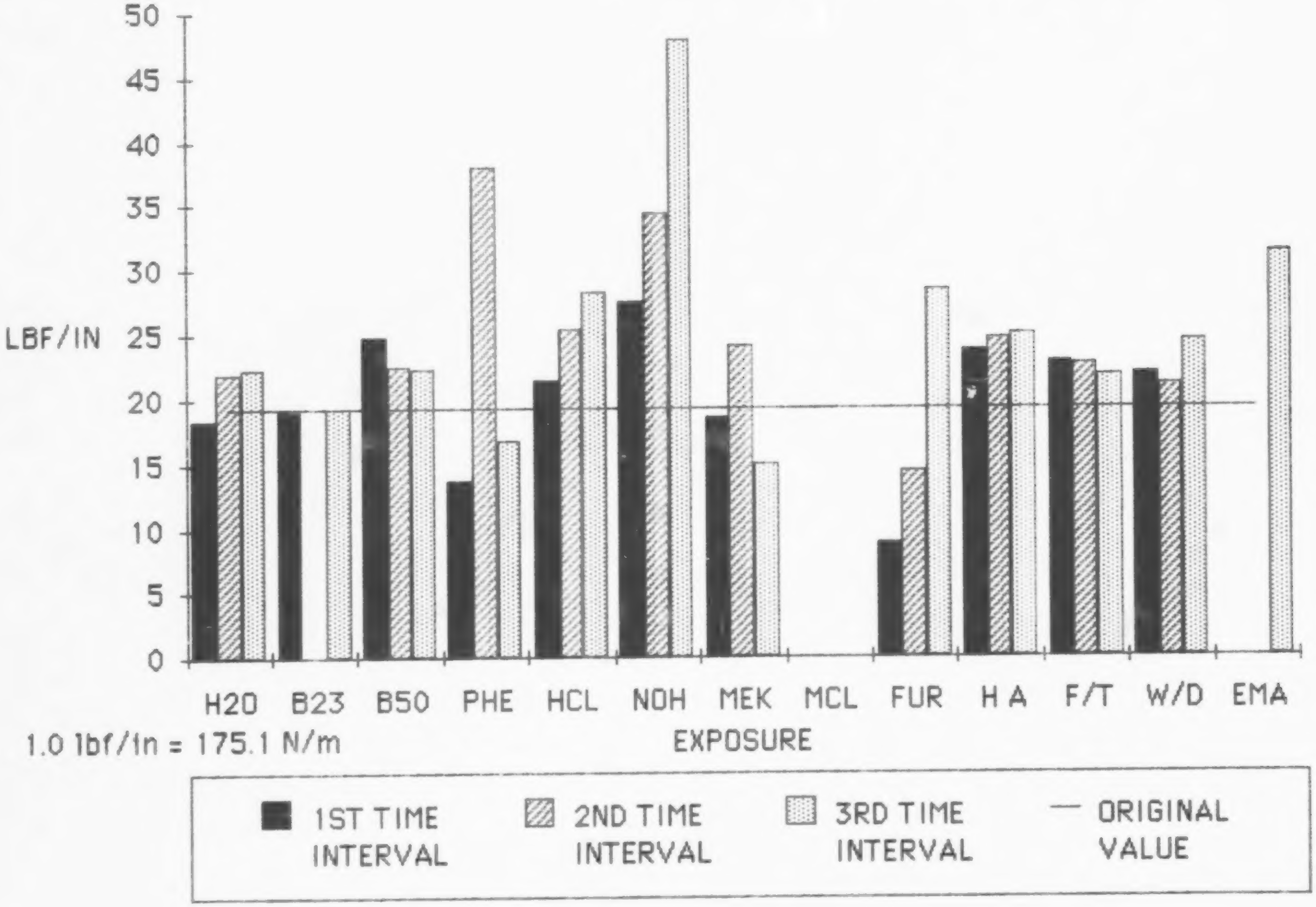


Figure 101. SEAM SHEAR STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL PVC (U) - SAMPLE 37

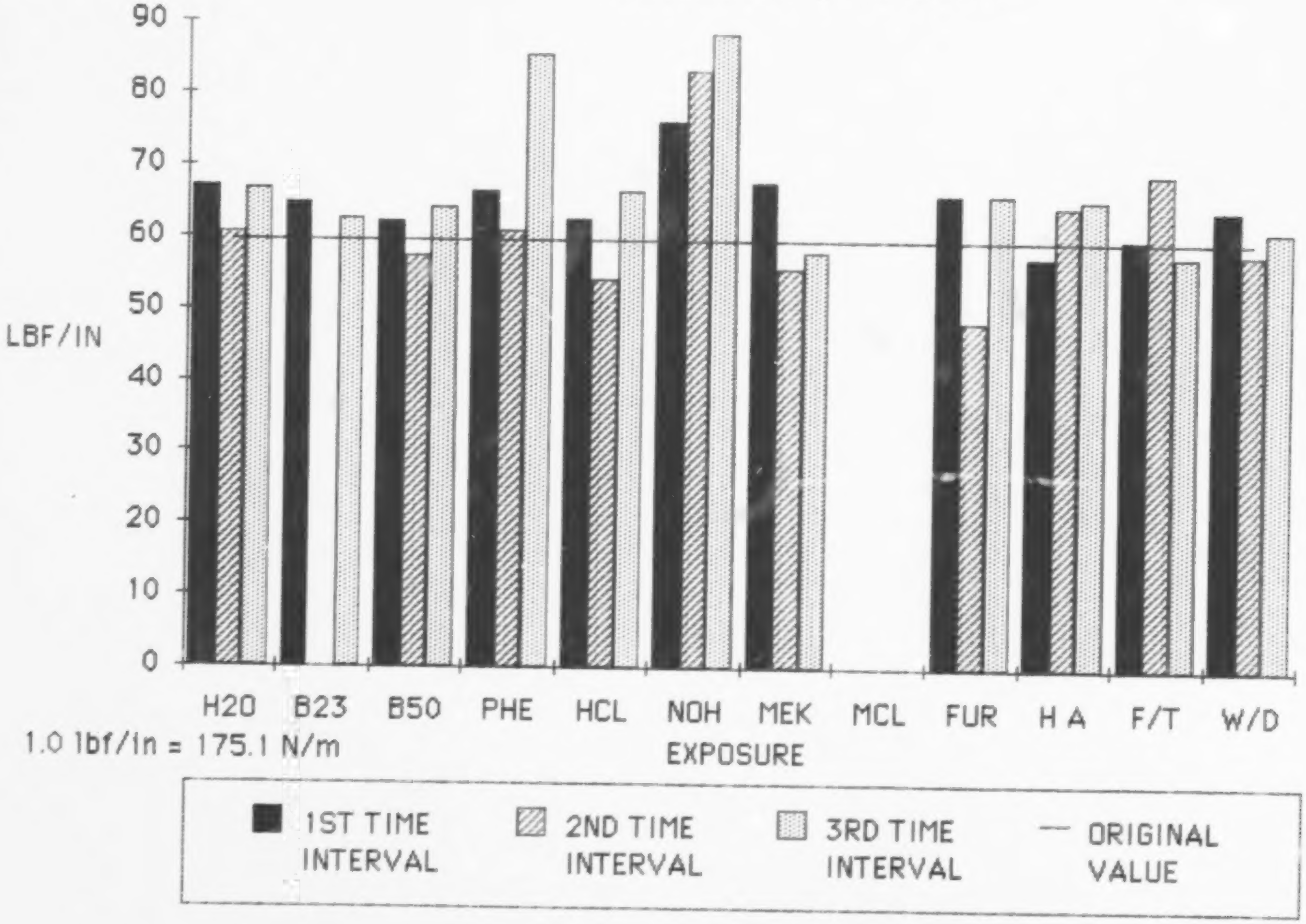
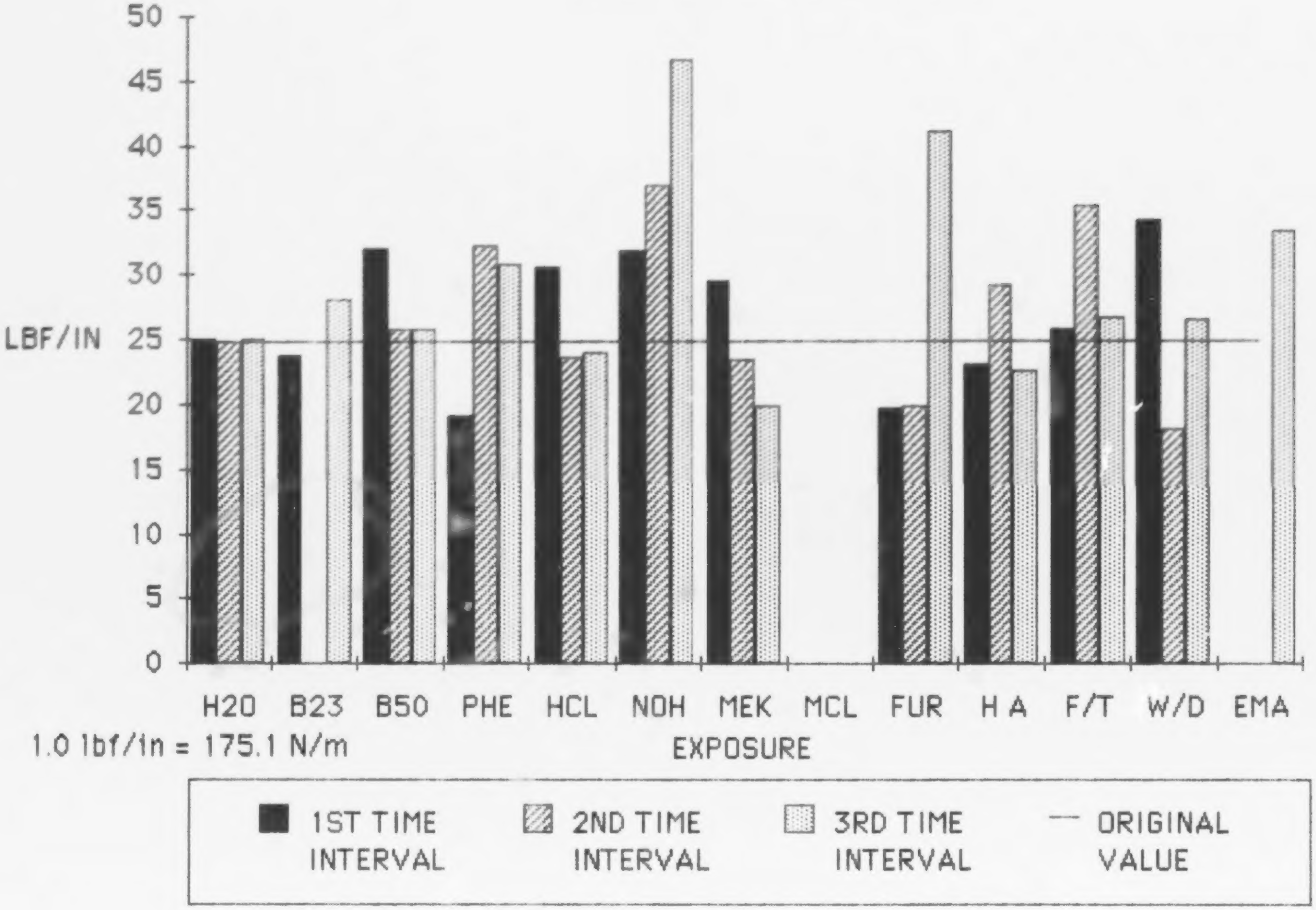


Figure 102. SEAM PEEL STRENGTH - SOLVENT ADHESIVE FIELD SEAM - 30 MIL PVC (U) - SAMPLE 37



1.0 lbf/in = 175.1 N/m

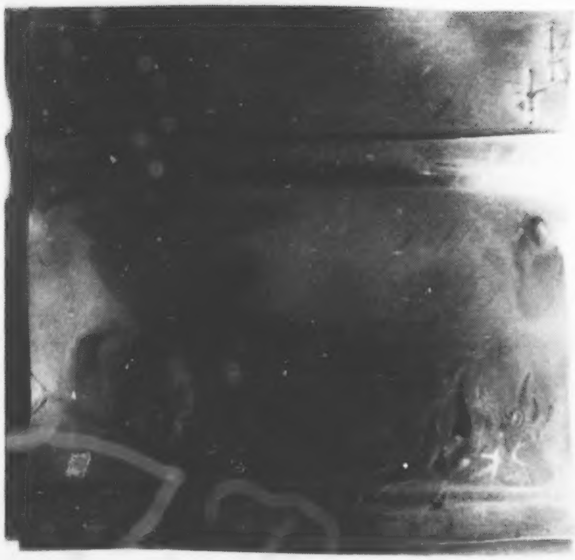


Figure 103. Results of 1-year EMMAQUA exposure for 30 mil LLDPE field seam (Sample 34). Sample has melted at two areas.

Figure 104. PERCENT WEIGHT CHANGE - 36 MIL CPE (S) - SAMPLE A

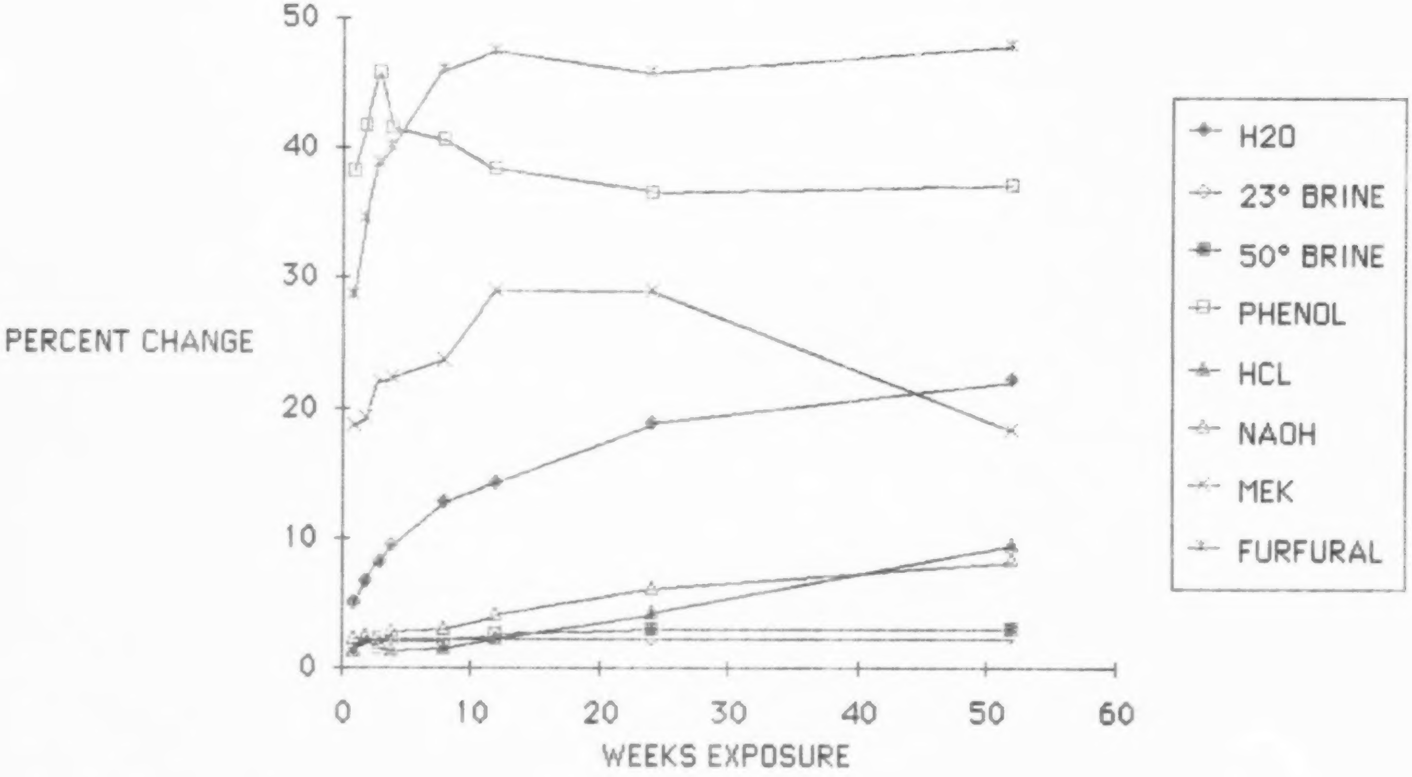


Figure 105. PERCENT WEIGHT CHANGE - 36 MIL CPE (S) - SAMPLE B

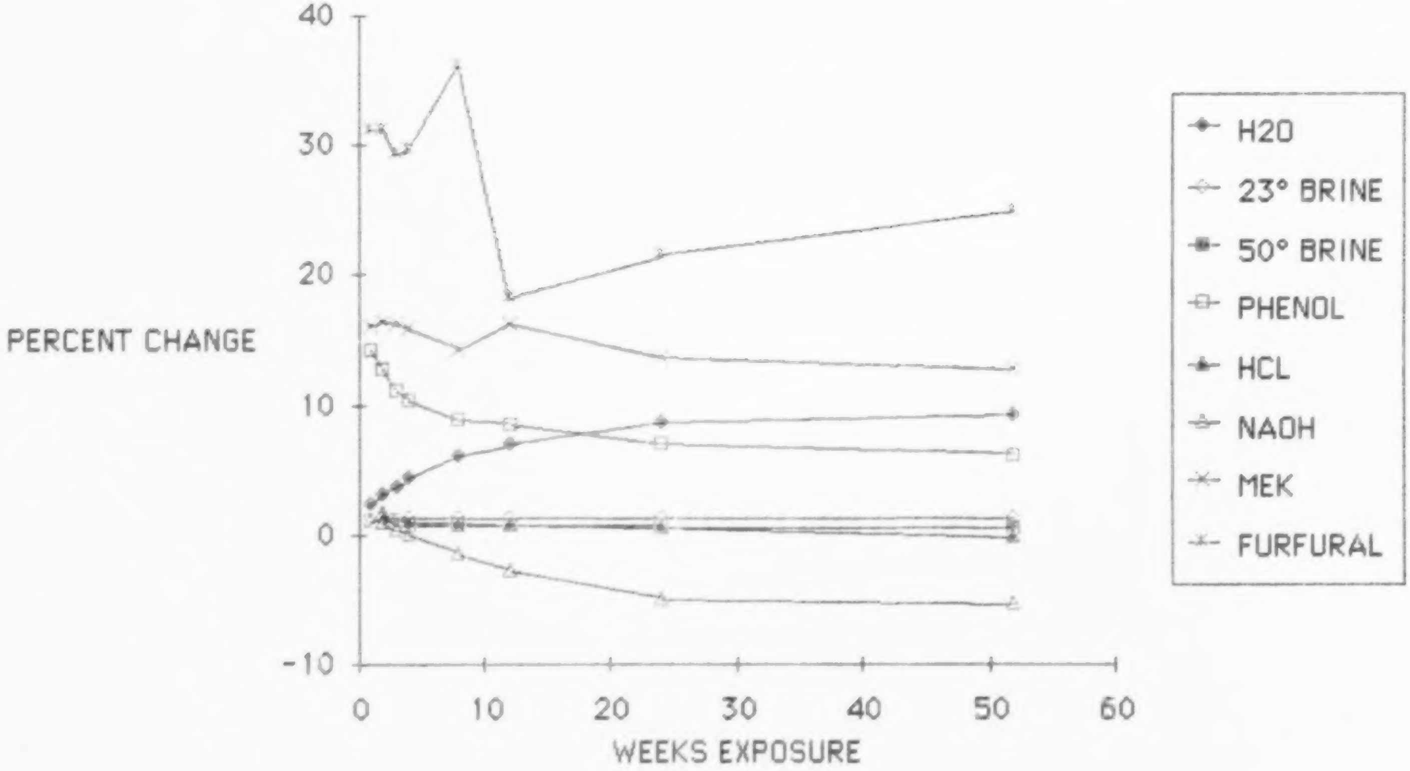


Figure 106. PERCENT WEIGHT CHANGE - 30 MIL CSPE (S) - SAMPLE C

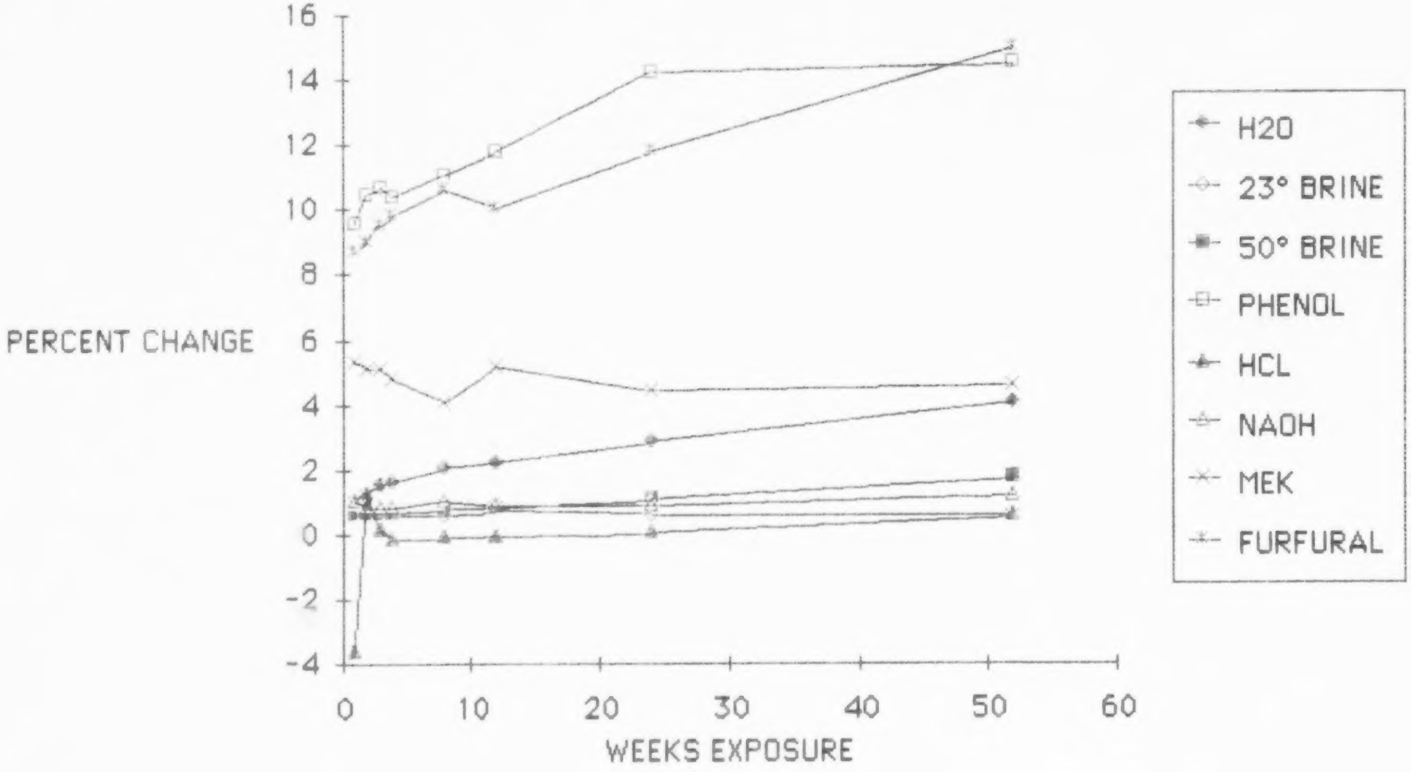


Figure 107. PERCENT WEIGHT CHANGE - 36 MIL CSPE (S) - SAMPLE D

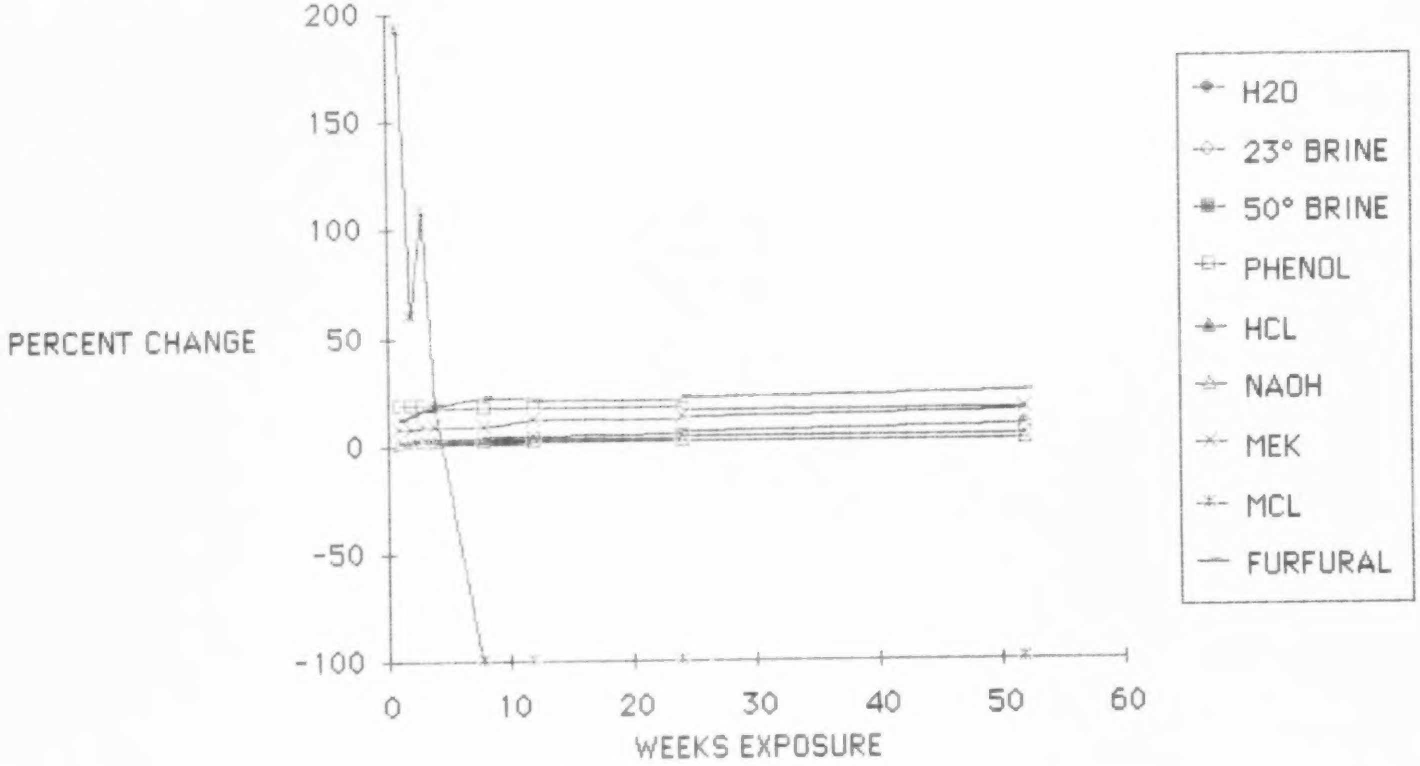


Figure 108. PERCENT WEIGHT CHANGE - 36 MIL CSPE (S) - SAMPLE E

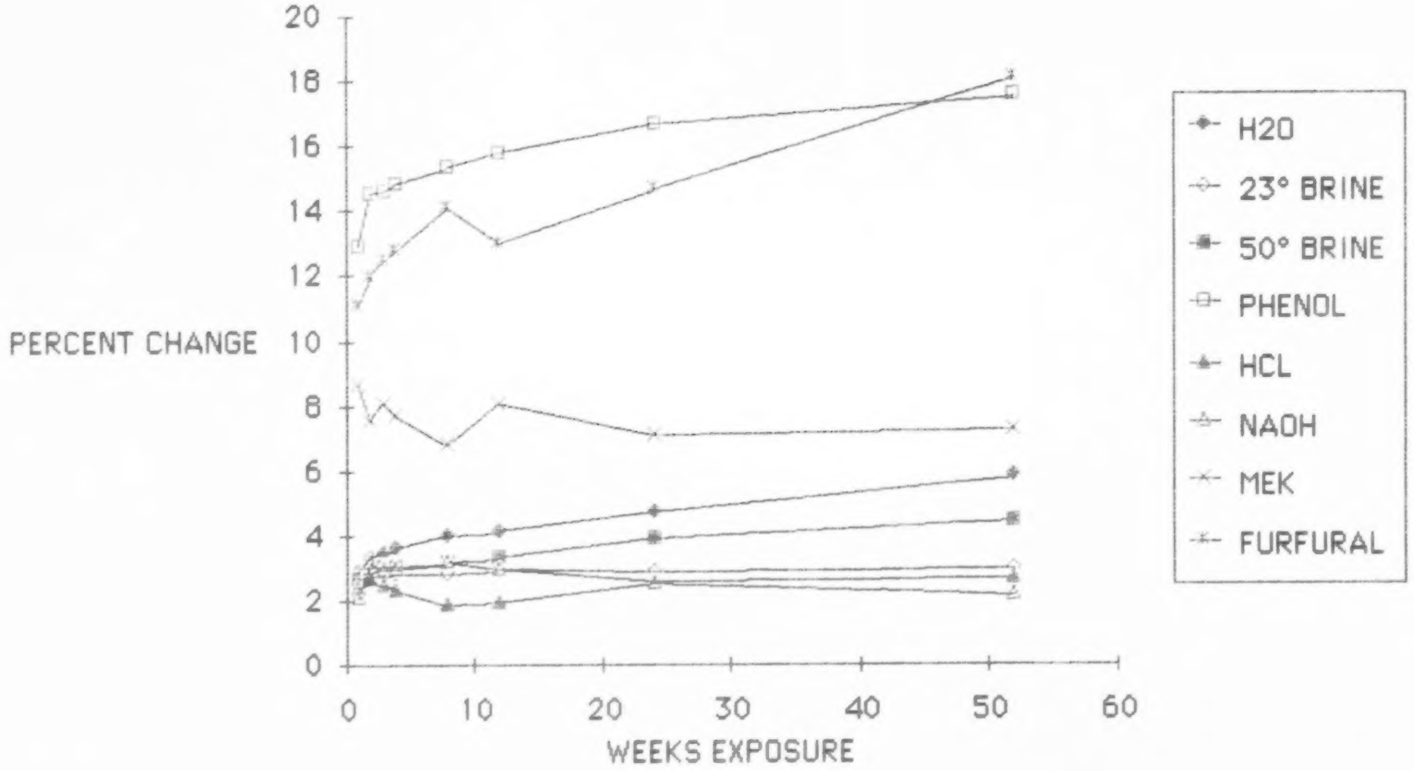


Figure 109. PERCENT WEIGHT CHANGE - 36 MIL CSPE (S) - SAMPLE F

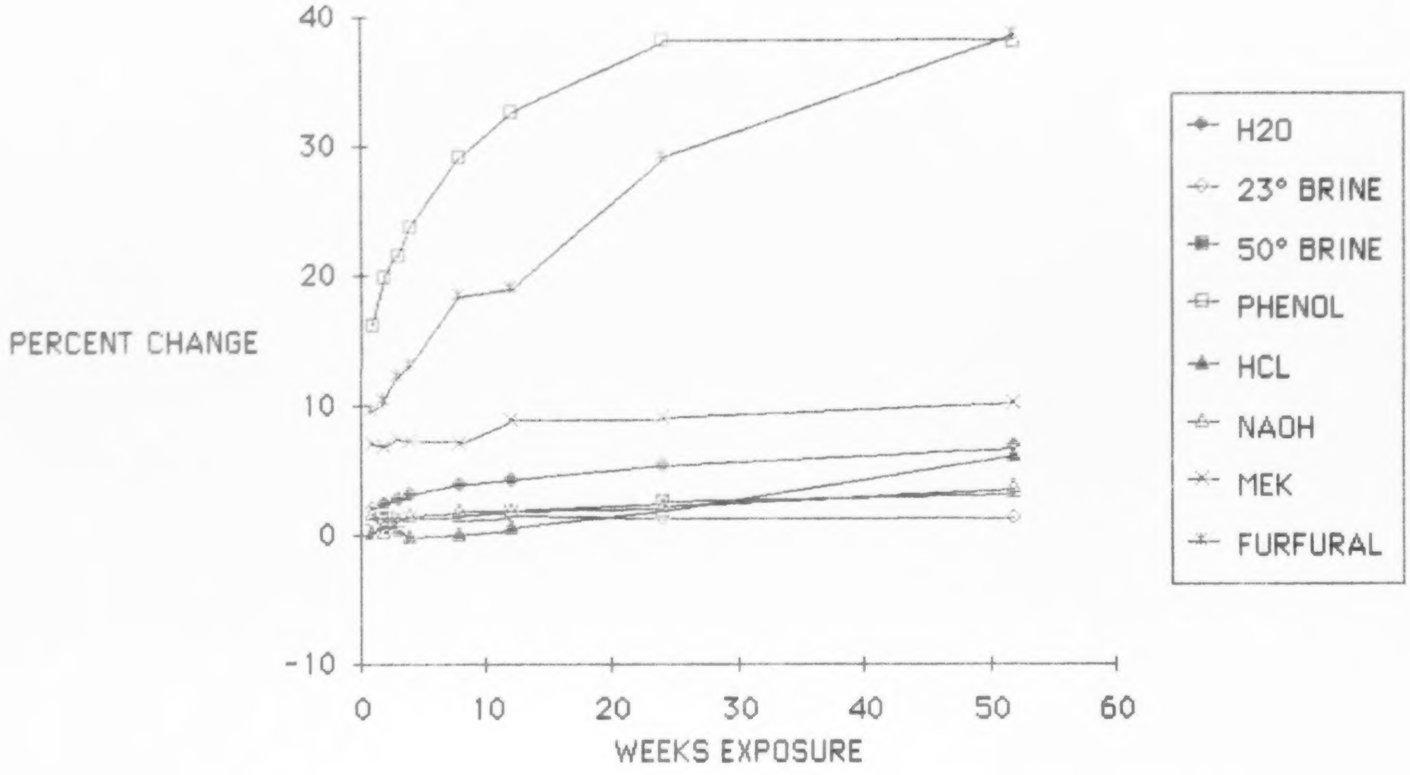


Figure 110. PERCENT WEIGHT CHANGE - 36 MIL CSPE (S) - SAMPLE G

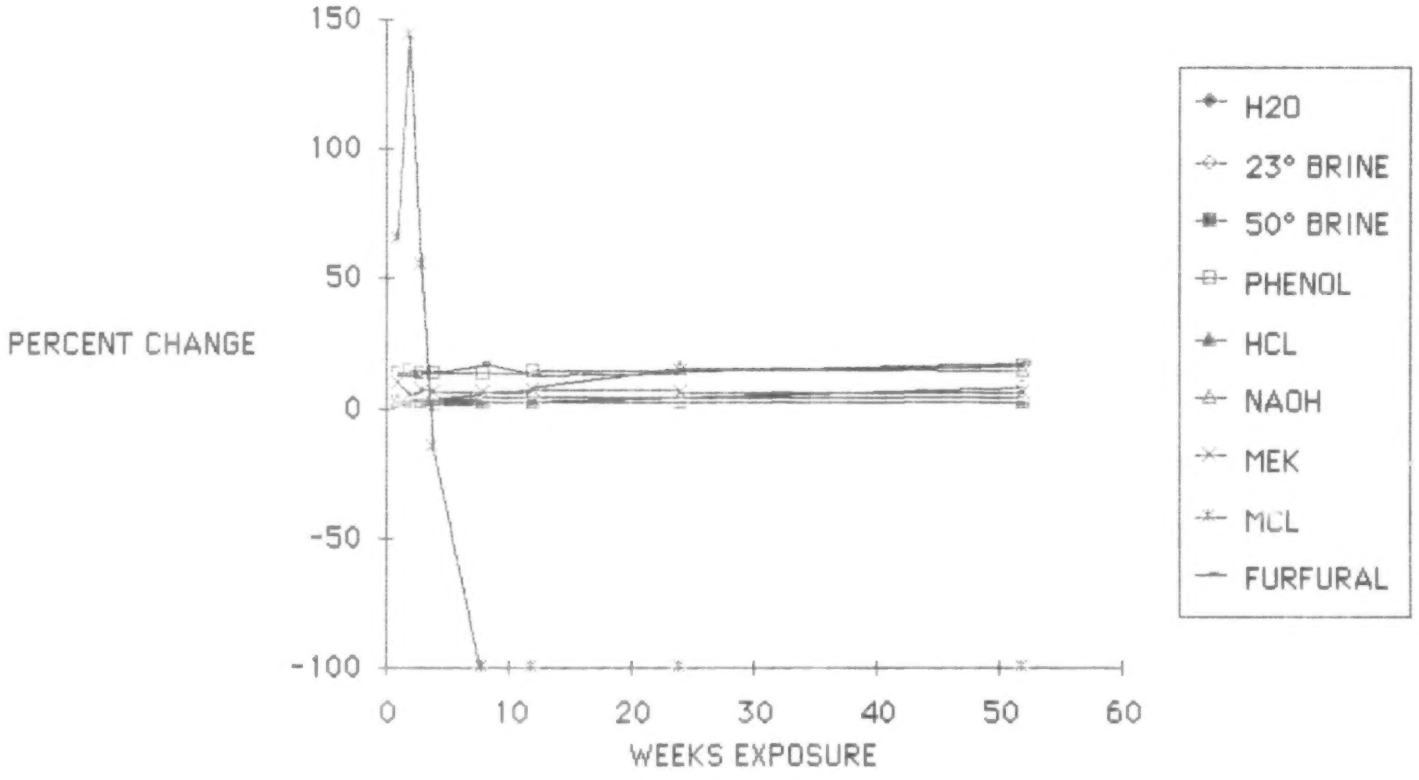


Figure 111. PERCENT WEIGHT CHANGE - 36 MIL CSPE (S) - SAMPLE H

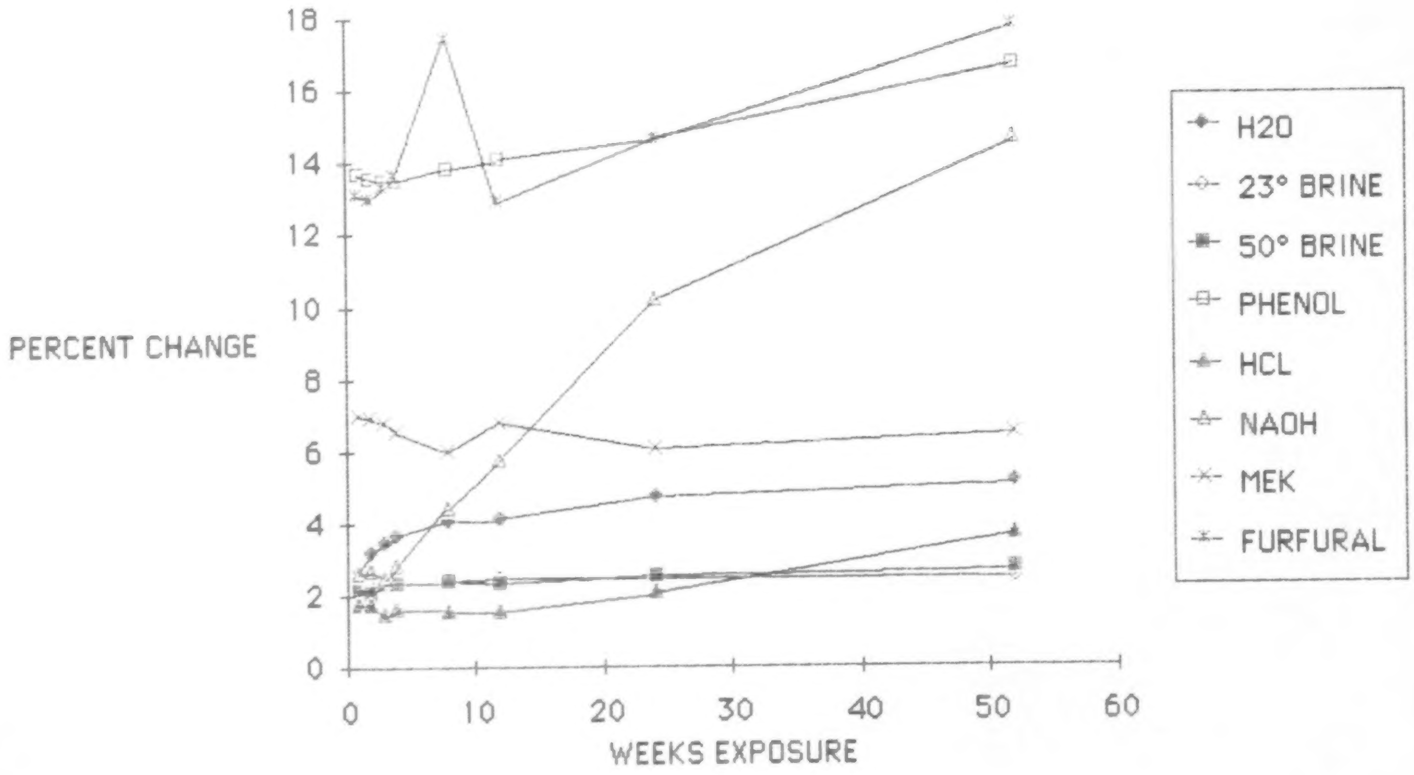


Figure 112. PERCENT WEIGHT CHANGE - 36 MIL CSPE (S) - SAMPLE I

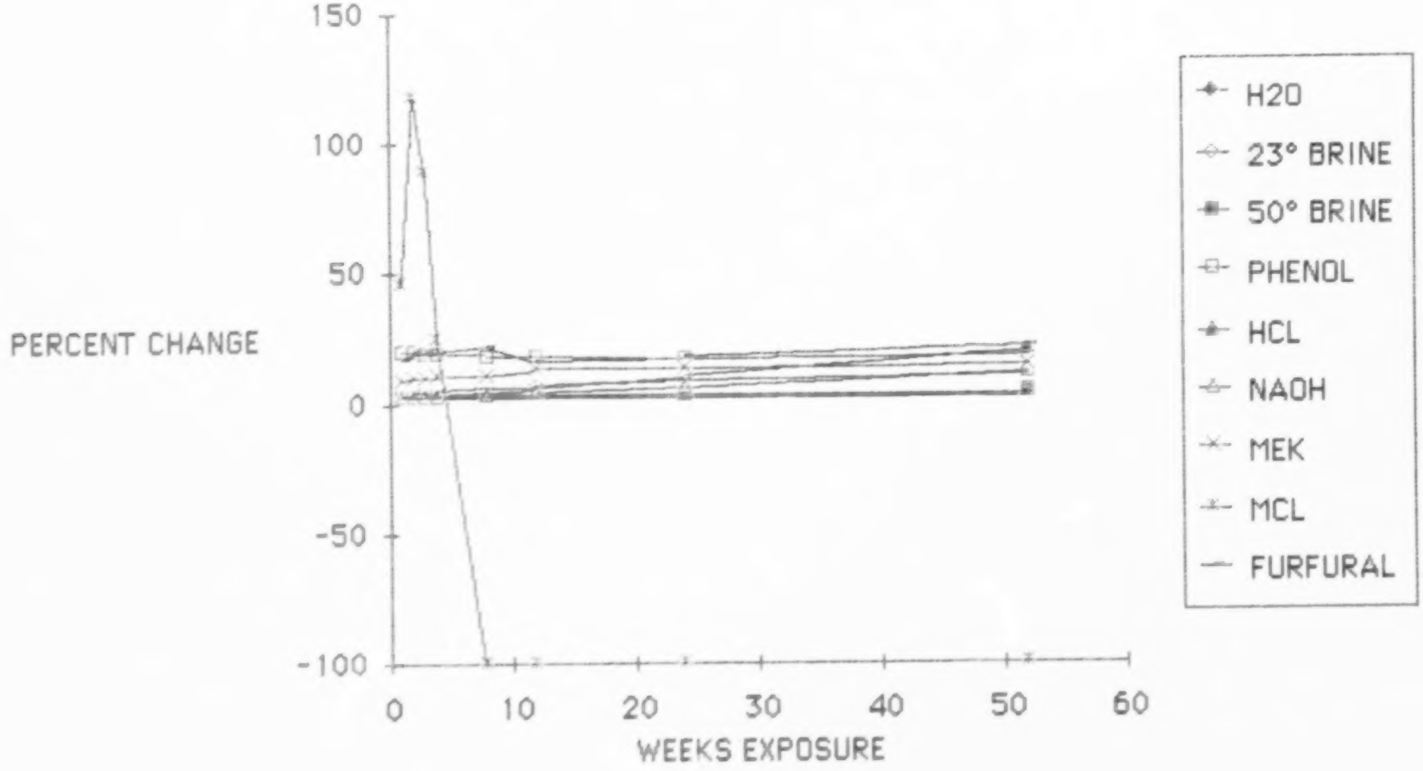


Figure 113. PERCENT WEIGHT CHANGE - 38 MIL EIA (S) - SAMPLE J

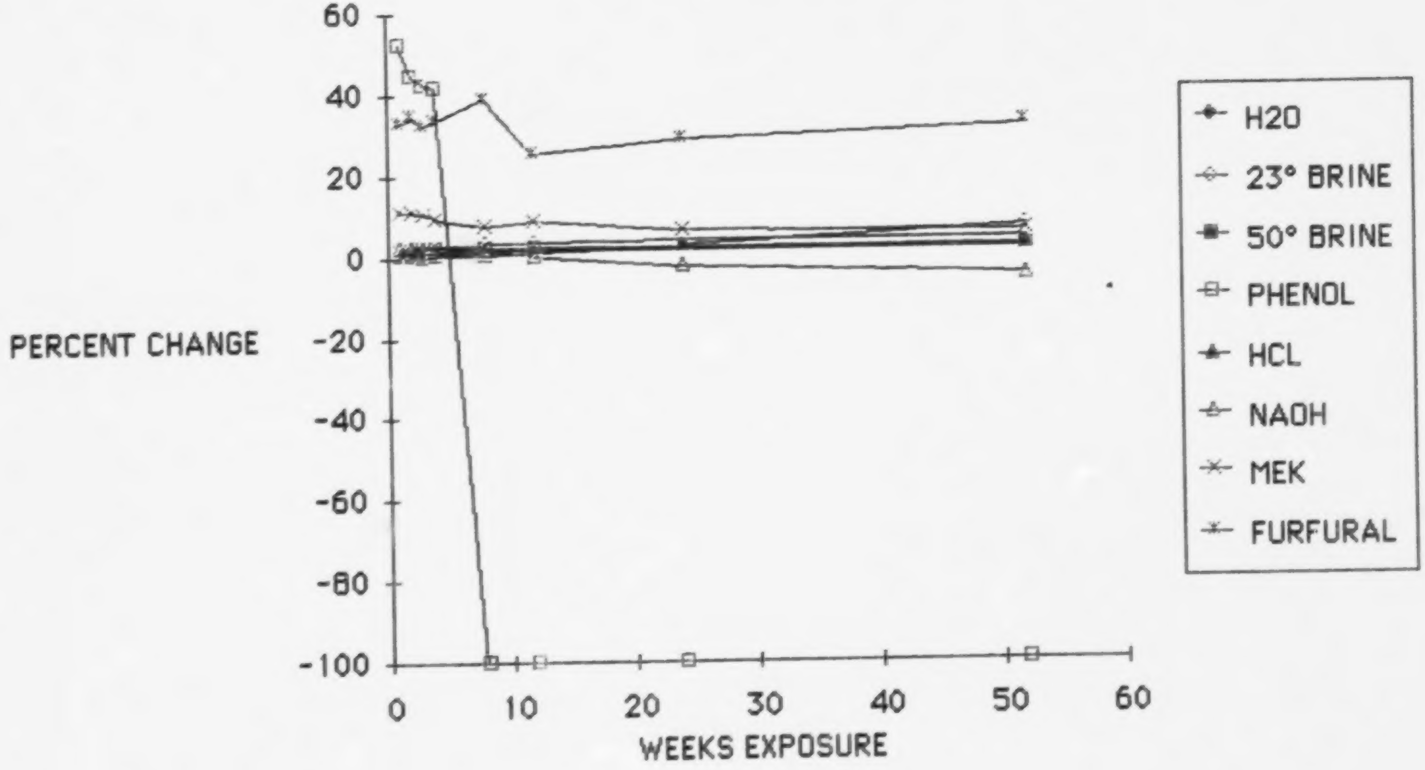


Figure 114. PERCENT WEIGHT CHANGE - 40 MIL EPDM (U) - SAMPLE K

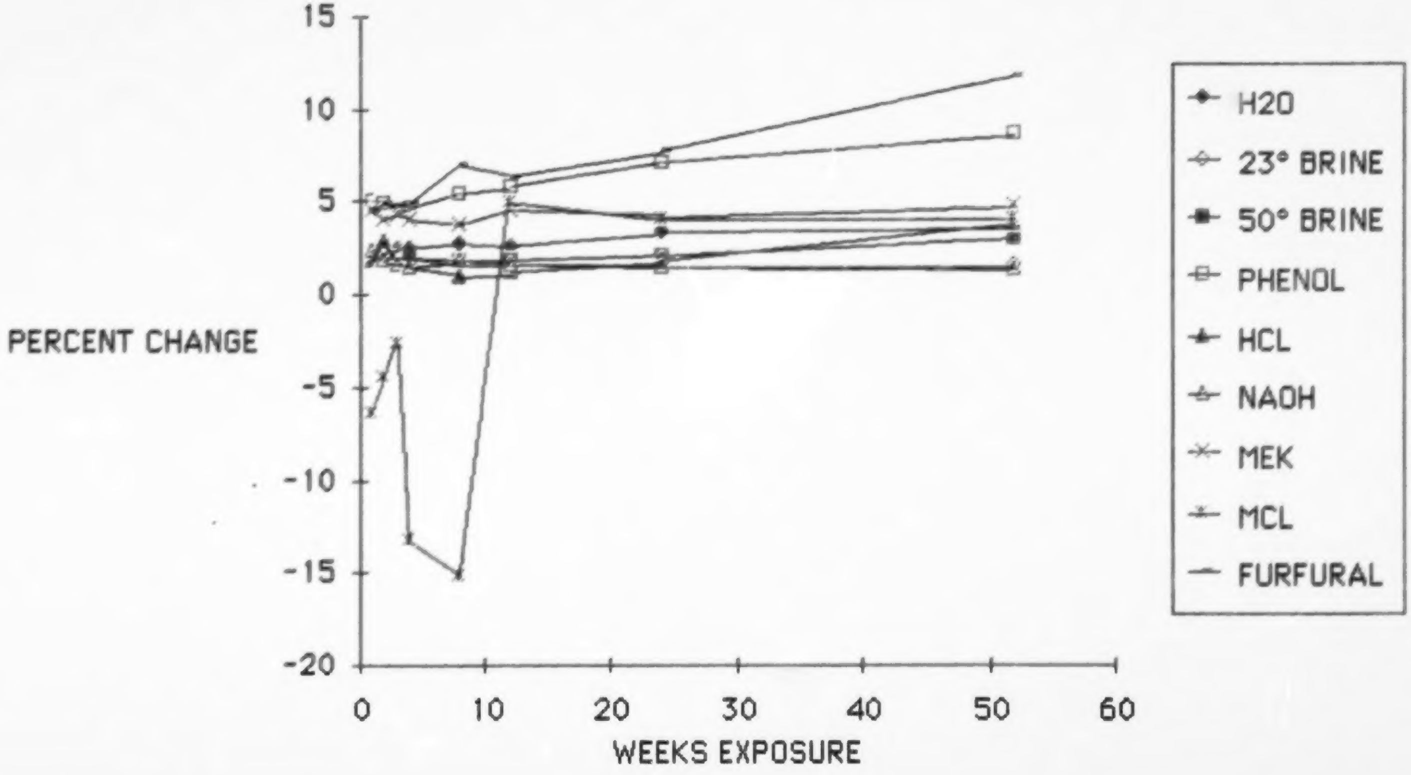


Figure 115. PERCENT WEIGHT CHANGE - 30 MIL CPE (U) - SAMPLE L

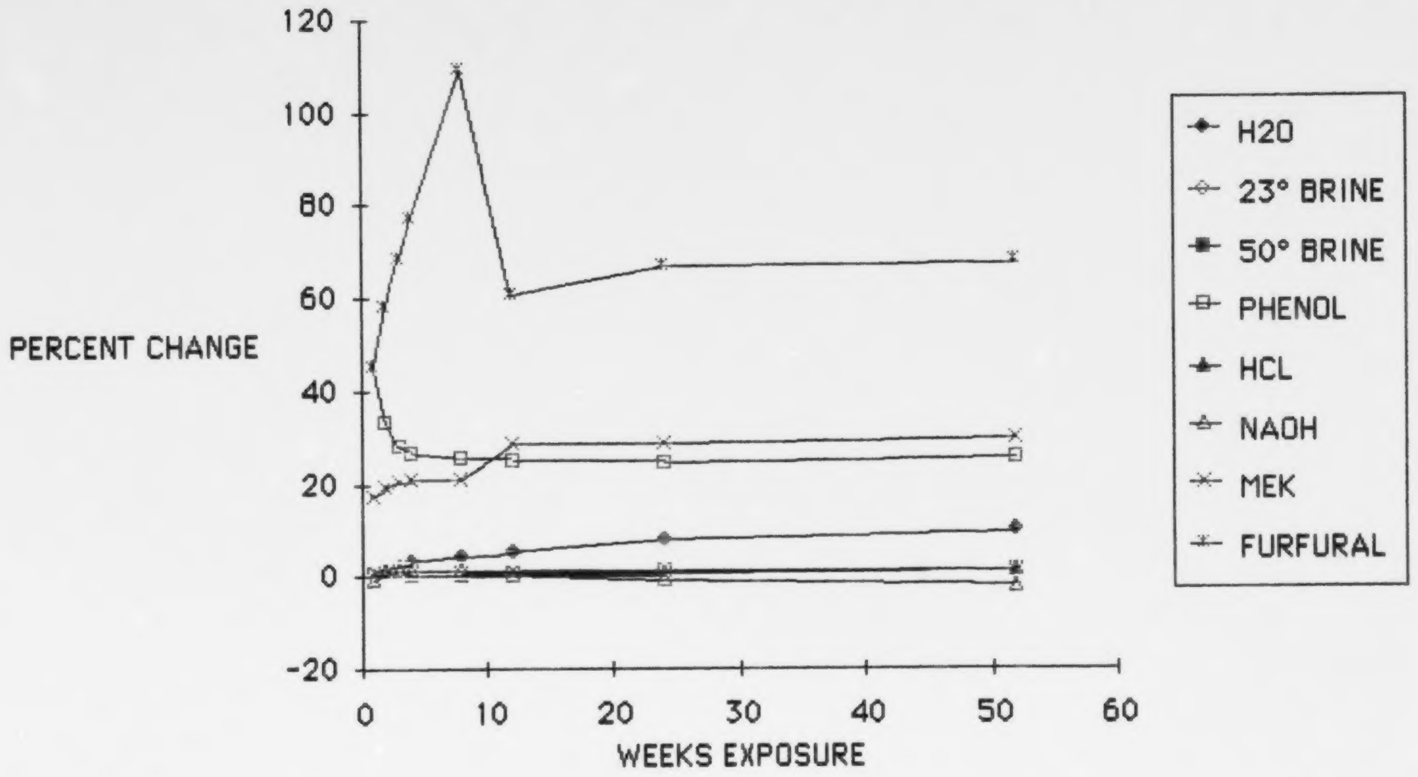


Figure 116. PERCENT WEIGHT CHANGE - 30 MIL CPE (U) - SAMPLE M

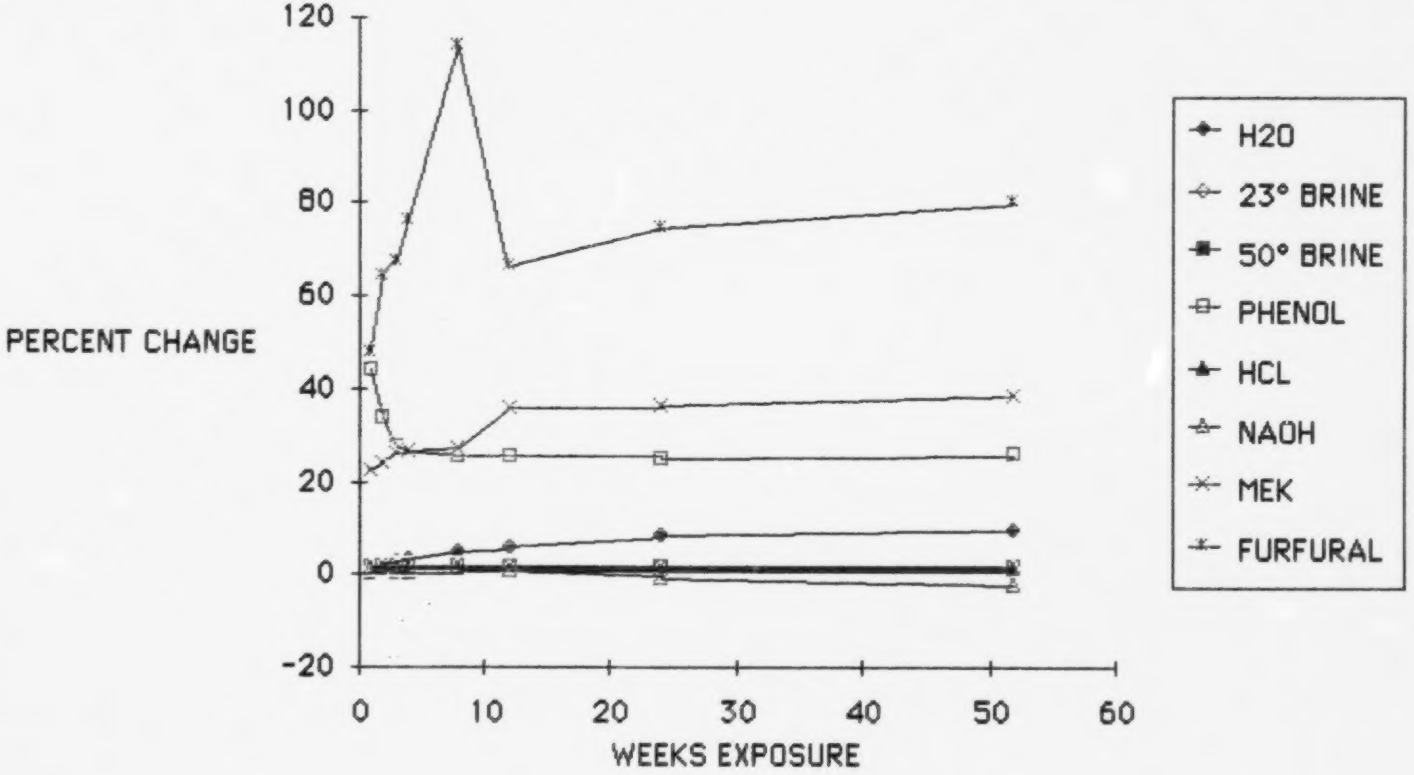


Figure 117. PERCENT WEIGHT CHANGE - 30 MIL HDPE (U) - SAMPLE N

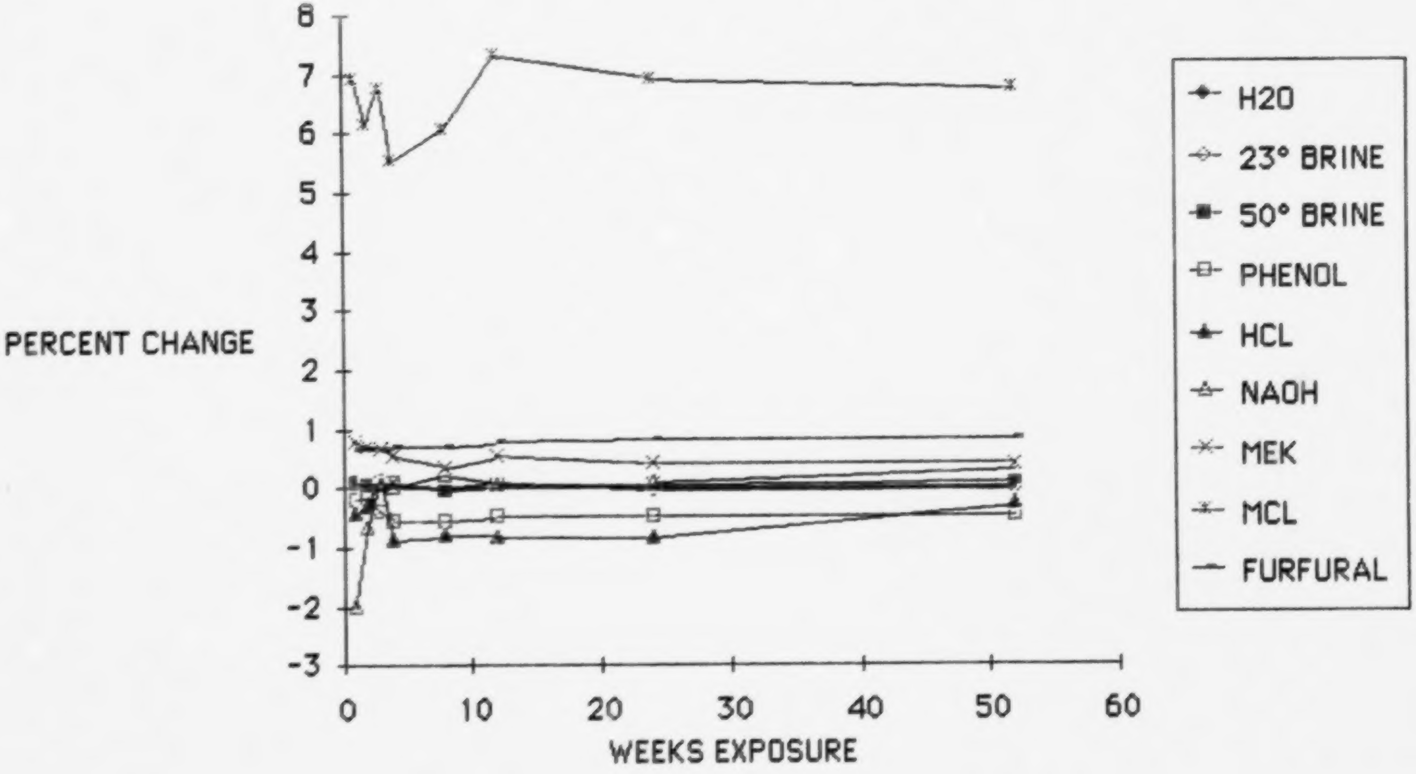


Figure 118. PERCENT WEIGHT CHANGE -
80 MIL HDPE (U) - SAMPLE O

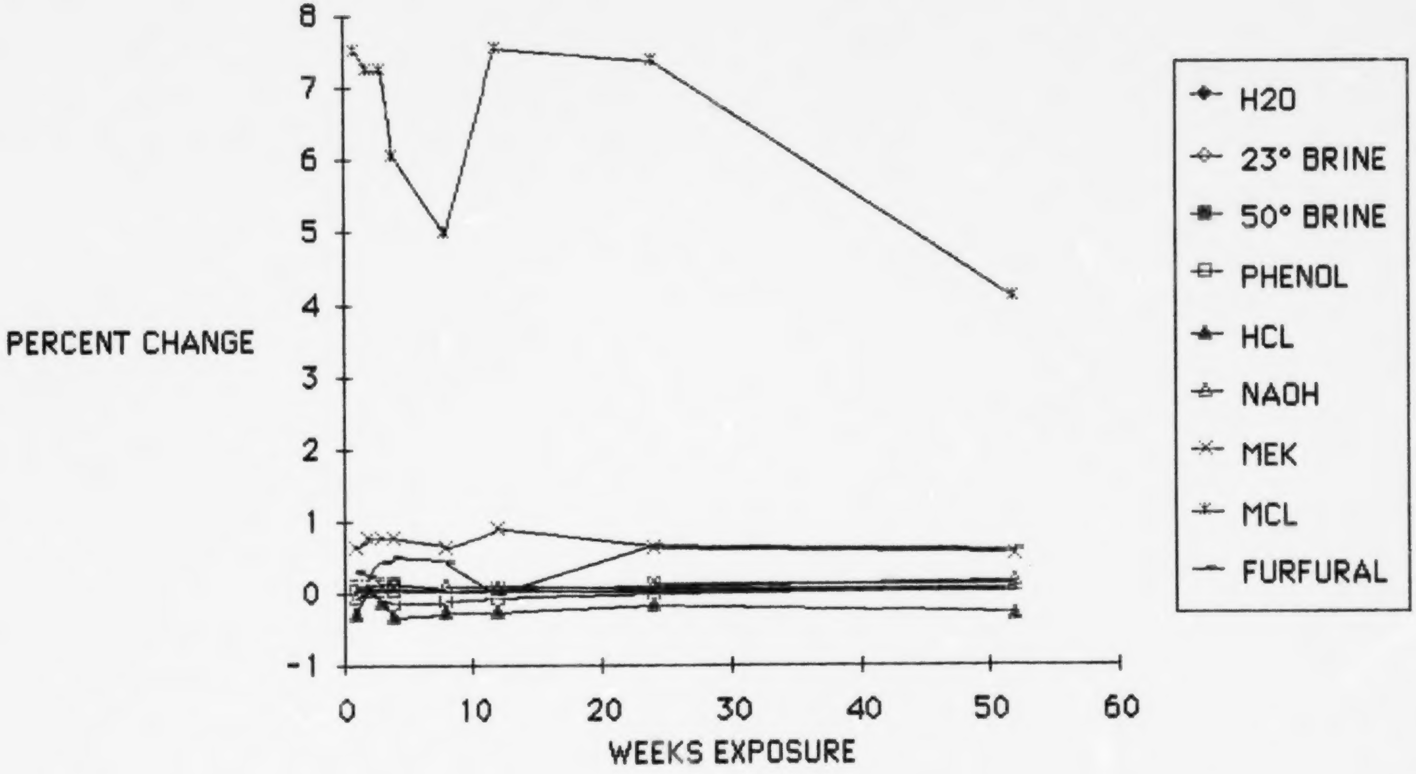


Figure 119. PERCENT WEIGHT CHANGE - 80 MIL HDPE (U) - SAMPLE P

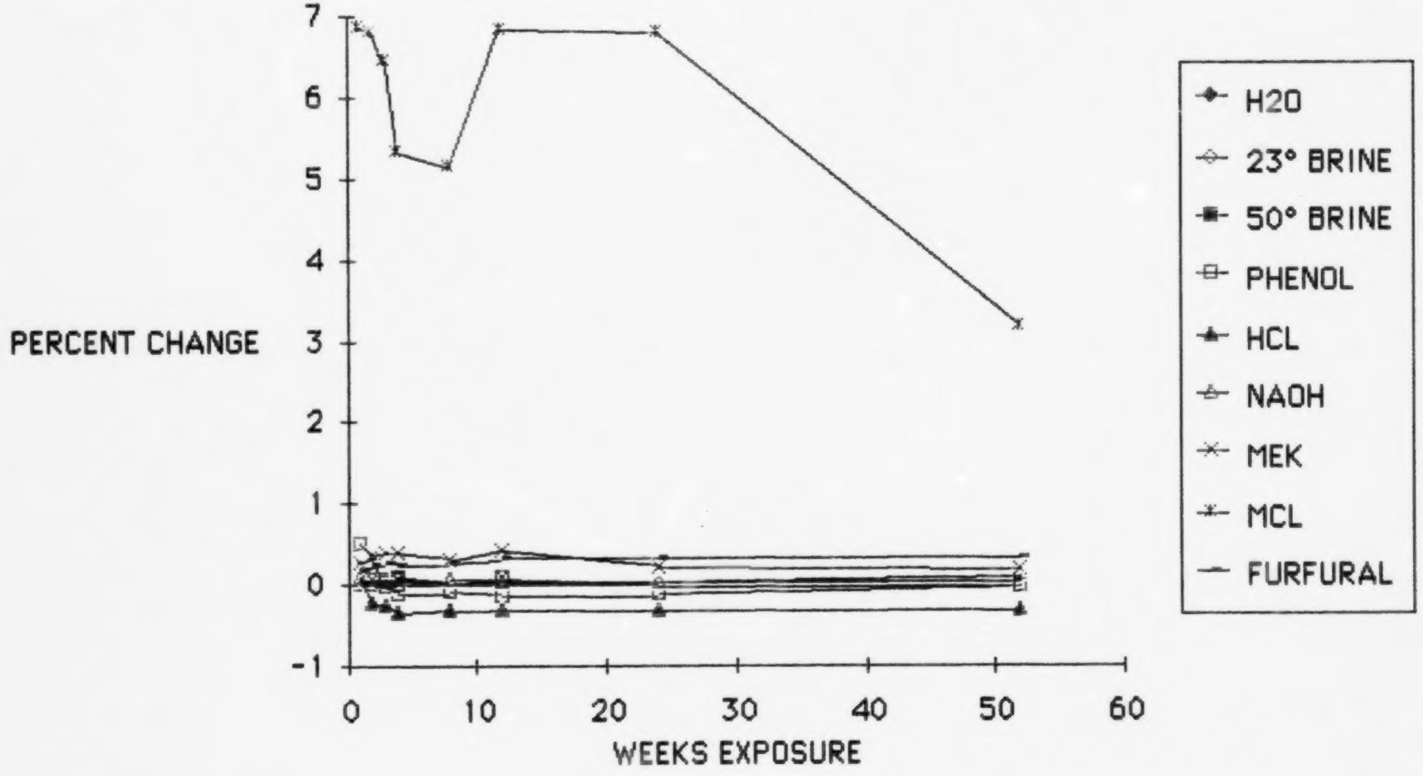


Figure 120. PERCENT WEIGHT CHANGE - 80 MIL HDPE (U) - SAMPLE Q

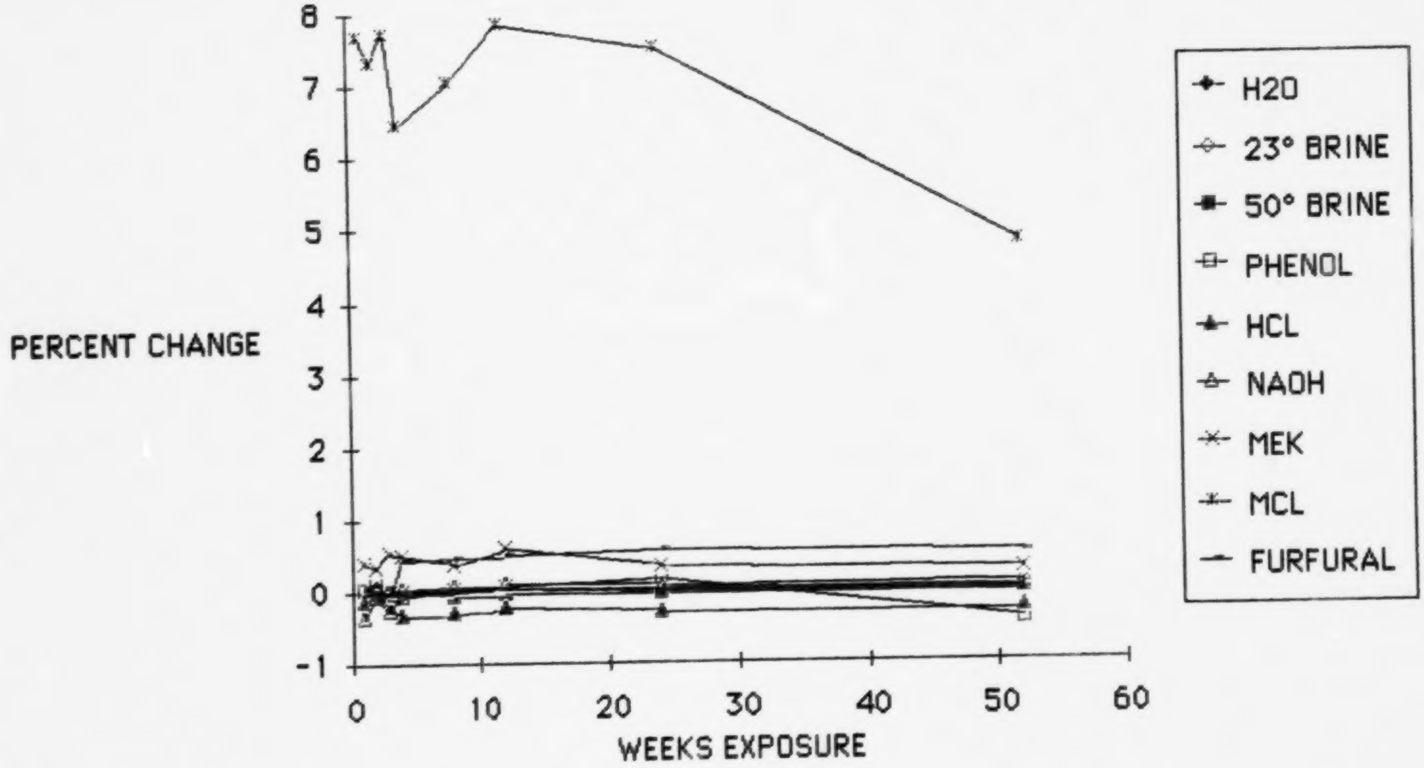


Figure 121. PERCENT WEIGHT CHANGE - 30 MIL LLDPE (U) - SAMPLE R

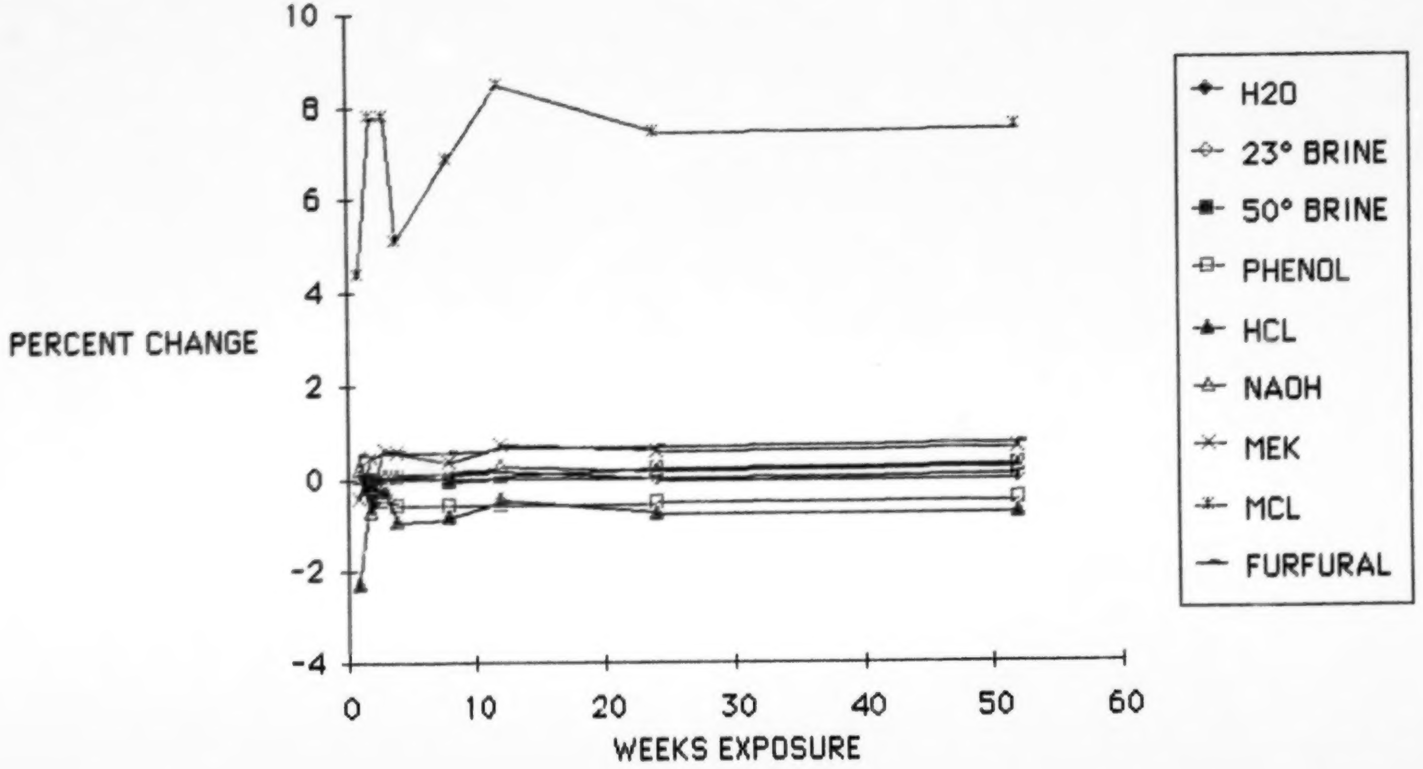


Figure 122. PERCENT WEIGHT CHANGE - 30 MIL PVC (U) - SAMPLE S

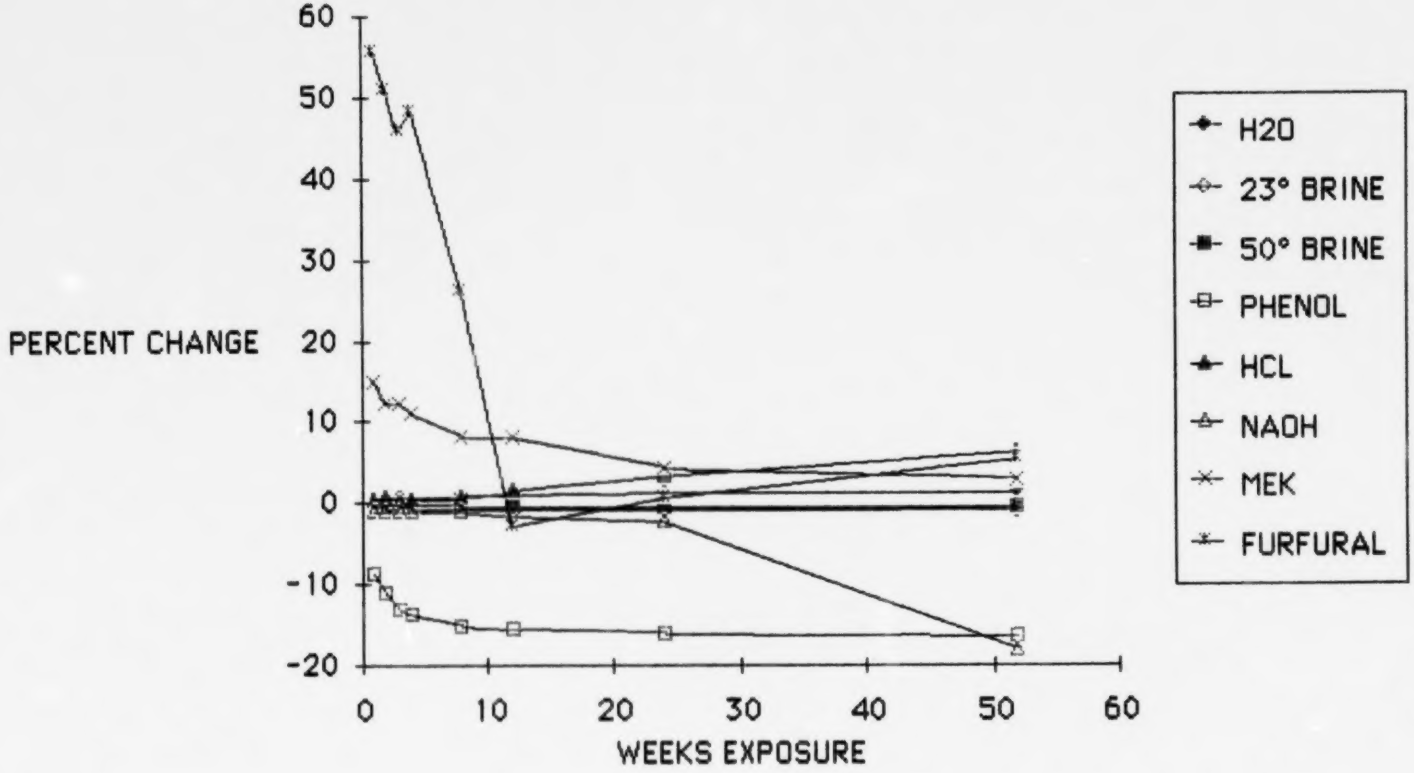


Figure 123. PERCENT WEIGHT CHANGE - 30 MIL PVC (U) - SAMPLE T

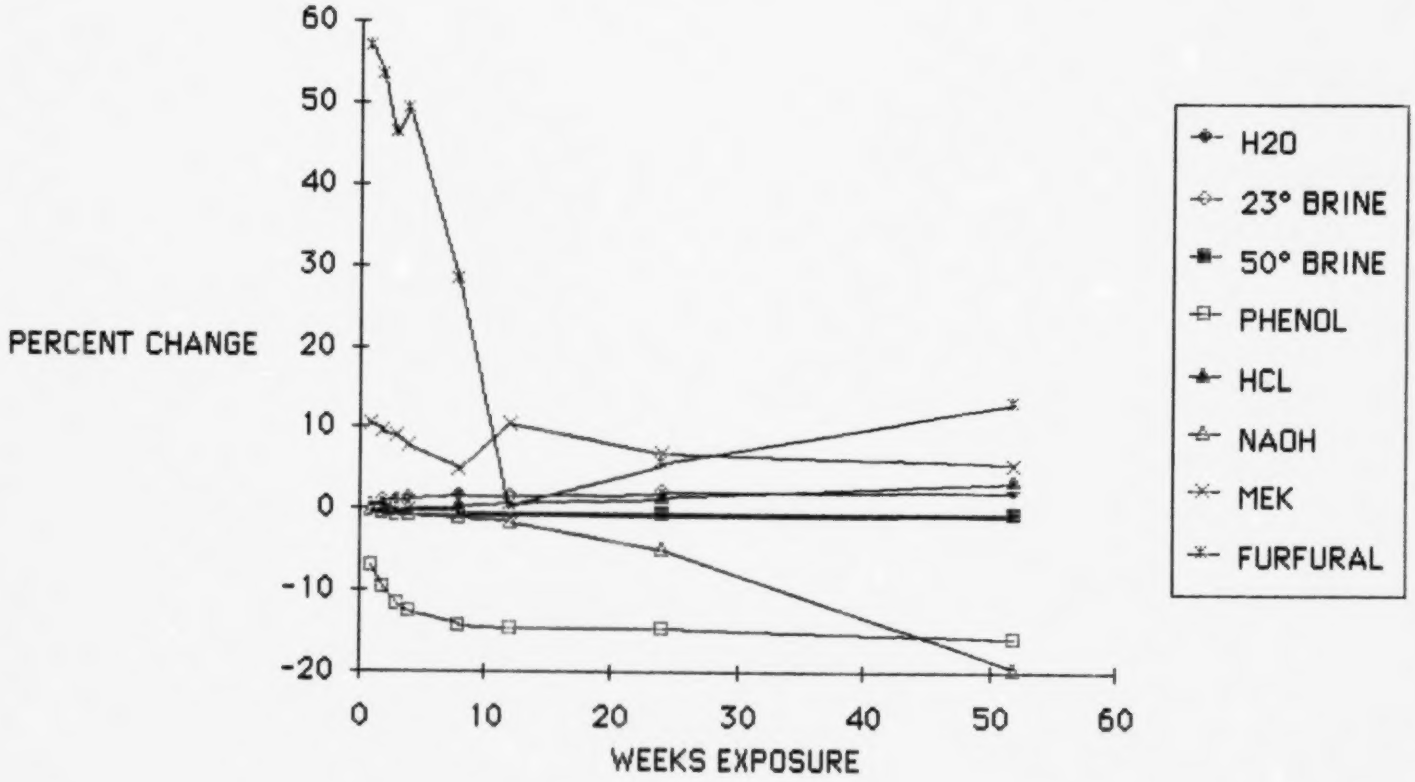
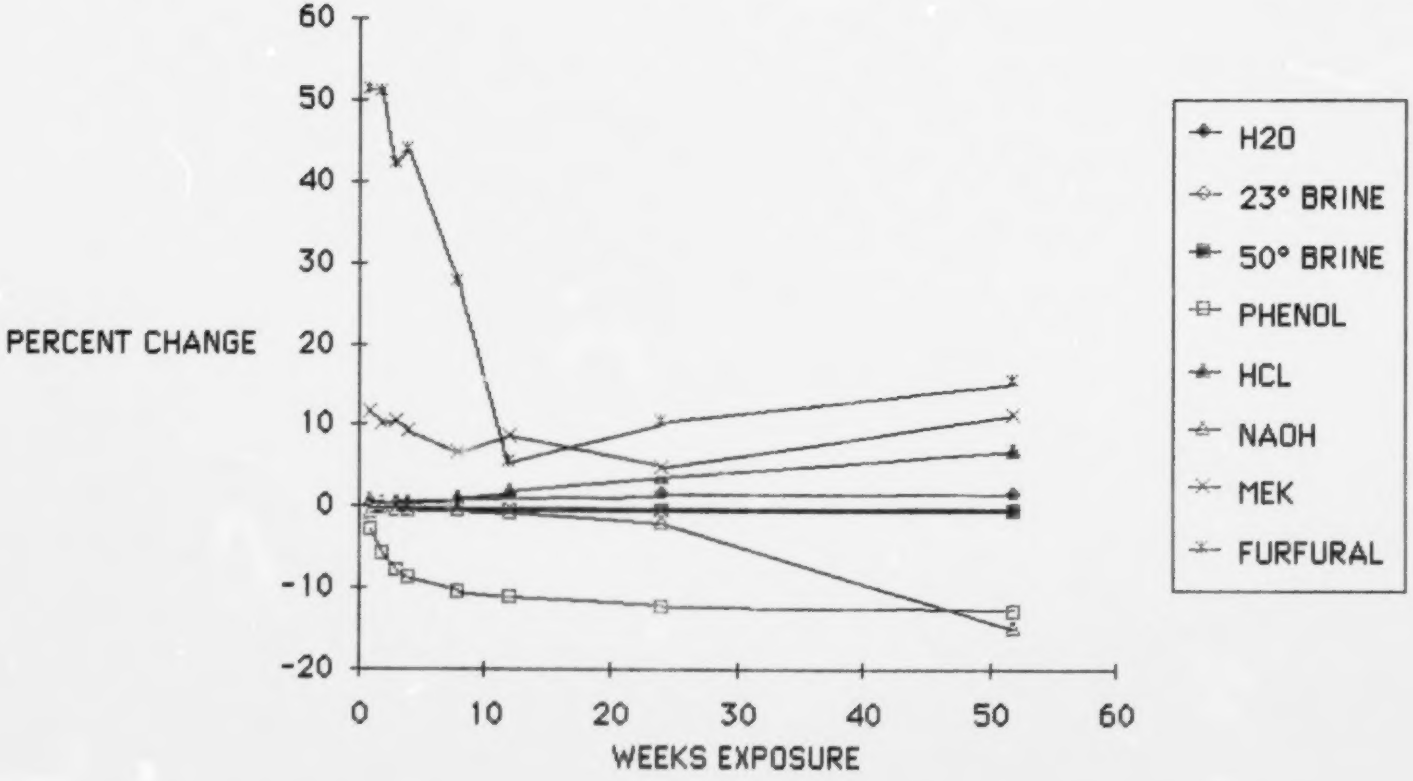


Figure 124. PERCENT WEIGHT CHANGE - 30 MIL PVC (U) - SAMPLE U



SECTION 8

PERFORMANCE OF SEAMS

General

The performance of the individual seams is summarized in table 3 for chemical immersion and in table 4 for the remaining exposure conditions. The performance is rated satisfactory (S), unsatisfactory (U), or questionable (Q) indicating that additional testing is needed to determine suitability. For example, several CSPE materials exhibited a significant increase in shear strength after exposure to heat aging and/or brine exposure at 50 °C. Additional testing is required to determine what effect this type of exposure would have on the other physical properties such as tear strength, puncture resistance and dimensional stability.

Performance was considered unsatisfactory if there was over a 20 percent loss in either shear or peel strength of the seams after exposure, or if the particular exposure caused adverse effects such as stiffening, shrinkage, wrinkling or blistering of the material.

The appearance of the seam samples after 12 months of chemical immersion is shown in Figures 1 through 80 in the Appendix.

The following paragraphs describe the performance of the individual seams after exposure to the various environmental conditions.

Sample 1, 36 mil CPE(S) - Thermal Hot Air Factory Seam

Test results are shown in Figures 29 and 30, and table 1 in the Appendix. Except for heat aging and brine immersion at 50 °C, this seam exhibited a significant decrease of over 50 percent in its shear strength after exposure to the various conditions. A slight increase in shear strength occurred after heat aging and brine exposure at 50 °C. There was also a decrease in peel strength but not to the same degree as noted for shear. The failure mode for both shear and peel was primarily scrim break within the seam (mode 7).

For chemical immersion, the samples were destroyed by the methylene chloride. Of the remaining chemicals, phenol followed by sodium hydroxide produced the most detrimental effects. Exposure to phenol caused some blistering as shown in Figure 1 in the Appendix.

Sample 2, 36 mil CPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 31 and 32, and table 2 in the Appendix. Except for exposure to some chemicals, this seam generally performed satisfactorily. There was about a 15 to 25 percent increase in its shear strength after exposure to the various conditions. The failure mode for shear was primarily scrim break within the seam (mode 7). Very little change occurred to the peel strength with planar failure within the seam (mode 4) being the most predominant mode of failure.

For chemical immersion, the samples were destroyed by the methylene, chloride. Exposure to phenol, methyl ethyl ketone and furfural caused some blistering, while the exposure to the other chemicals produced some stiffening of this material.

Sample 3, 30 mil CSPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 33 and 34, and table 3 in the Appendix. This seam performed satisfactorily except for exposure to methylene chloride, sodium hydroxide, phenol and heat aging. Very little change occurred to either the shear or peel strengths for samples subjected to the other exposure conditions. The failure mode for shear was scrim break within the seam (mode 7). Several different failure modes were observed in the peel tests with mode 7 being the most predominant.

After exposure to heat aging, there was about a 25 percent increase in shear strength coupled with a 33 percent decrease in peel strength. Also, the failure in peel was ply separation (mode 8) as compared to failure at the seam edge (mode 2) for the unaged material.

For chemical immersion, the samples were destroyed by the methylene chloride. Exposure to sodium hydroxide produced a 38 percent reduction in shear strength coupled with about a 24 percent reduction in peel strength. Exposure to phenol produced about a 20 percent reduction in both shear and peel strength. Some discoloration occurred to the sample exposed to furfural as shown in Figure 65 in the Appendix.

Sample 4, 36 mil CSPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 35 and 36, and table 4 in the Appendix. This seam exhibited a decrease in shear strength except for those samples subjected to conditions involving elevated temperatures, i.e., brine exposure at 50 °C and heat aging. For the brine samples, the seam strength increased about 37 percent, and for the heat aging samples a 50 percent increase was observed. However, a significant decrease in peel strength of over 90 percent occurred to both groups of samples. The failures for both groups occurred within the seam (mode 4)

Sample 2, 36 mil CPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 31 and 32, and table 2 in the Appendix. Except for exposure to some chemicals, this seam generally performed satisfactorily. There was about a 15 to 25 percent increase in its shear strength after exposure to the various conditions. The failure mode for shear was primarily scrim break within the seam (mode 7). Very little change occurred to the peel strength with planar failure within the seam (mode 4) being the most predominant mode of failure.

For chemical immersion, the samples were destroyed by the methylene, chloride. Exposure to phenol, methyl ethyl ketone and furfural caused some blistering, while the exposure to the other chemicals produced some stiffening of this material.

Sample 3, 30 mil CSPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 33 and 34, and table 3 in the Appendix. This seam performed satisfactorily except for exposure to methylene chloride, sodium hydroxide, phenol and heat aging. Very little change occurred to either the shear or peel strengths for samples subjected to the other exposure conditions. The failure mode for shear was scrim break within the seam (mode 7). Several different failure modes were observed in the peel tests with mode 7 being the most predominant.

After exposure to heat aging, there was about a 25 percent increase in shear strength coupled with a 33 percent decrease in peel strength. Also, the failure in peel was ply separation (mode 8) as compared to failure at the seam edge (mode 2) for the unaged material.

For chemical immersion, the samples were destroyed by the methylene chloride. Exposure to sodium hydroxide produced a 38 percent reduction in shear strength coupled with about a 24 percent reduction in peel strength. Exposure to phenol produced about a 20 percent reduction in both shear and peel strength. Some discoloration occurred to the sample exposed to furfural as shown in Figure 65 in the Appendix.

Sample 4, 36 mil CSPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 35 and 36, and table 4 in the Appendix. This seam exhibited a decrease in shear strength except for those samples subjected to conditions involving elevated temperatures, i.e., brine exposure at 50 °C and heat aging. For the brine samples, the seam strength increased about 37 percent, and for the heat aging samples a 50 percent increase was observed. However, a significant decrease in peel strength of over 90 percent occurred to both groups of samples. The failures for both groups occurred within the seam (mode 4) as compared to scrim break within the seam (mode 7) for the unaged materials. The same exposure samples also failed in the dead load peel tests again with failure occurring within the seam (mode 4).

For chemical immersion, the samples were destroyed by the methylene chloride. The other chemicals also had an adverse effect to varying degrees on this sample.

Sample 5, 36 mil CSPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 37 and 38, and table 5 in the Appendix. A significant increase in shear strength was observed for the seam samples subjected to brine at 50 °C and heat aging. These same samples showed a decrease in peel strength. Consequently, this material would not be suitable for applications involving elevated temperatures. Except as discussed below, the primary mode of failure in shear was scrim break within the seam (mode 7), and ply separation (mode 8) was the failure mode in peel.

For chemical immersion, the samples were completely destroyed by the methylene chloride. Exposure to the HCl produced a significant increase in shear strength but the peel strength remained essentially unchanged. The other chemicals caused a significant reduction in shear strength and the mode of failure was scrim delamination (mode 5) as compared to scrim break within the seam (mode 7) for the unaged material. However, the effect on the peel strength was minimal.

Sample 6, 36 mil CSPE(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 39 and 40, and table 6 in the Appendix. Exposure to water produced a significant decrease of about 48 percent in shear strength within the first 3 months of immersion. However, very little change occurred to this property after the initial loss. The water immersion had very little effect on the peel strength of this seam. Similar performance was also observed for the samples subjected to freeze/thaw and wet/dry cycling.

For chemical immersion, the samples were destroyed by the methylene chloride. Exposure to the other chemicals produced a significant reduction in shear strength. Phenol was the most aggressive as indicated by nearly a 90 percent reduction in shear. The mode of failure in shear was scrim delamination (mode 5) as compared to failure in the parent material (mode 6) for the unaged samples. The peel strength properties were most adversely affected by exposure to phenol and furfural. The mode of peel failure was scrim delamination (mode 5) as compared to scrim break within the seam (mode 7) for the unaged materials.

Sample 7, 36 mil CSPE(S) - Solvent Adhesive Factory Seam

Test results are summarized in Figures 41 and 42, and in table 7 in the Appendix. A significant increase of over 50 percent in shear strength was observed for samples subjected to 50 °C brine and heat aging. These seam samples exhibited a decrease in peel strength of about 30 percent. Consequently this material would not be suitable for applications involving elevated temperatures.

Not including chemical immersion, this seam performed satisfactorily in the other environmental conditions. The primary mode of failure in shear was scrim break within the seam (mode 7) and ply separation mode 8) for peel.

For chemical immersion, the samples were destroyed by the methylene chloride. Exposure to sodium hydroxide produced the most adverse effect on the seam. The shear strength was decreased about 78 percent and the peel strength about 44 percent after 12 months of immersion. Some loss in seam strength also occurred to the samples exposed to the phenol. Performance in the other chemicals was generally satisfactorily.

Sample 8, 36 mil CSPE(S) - Thermal Dielectric Factory Seam

Test results are summarized in Figures 43 and 44, table 8 in the Appendix. An increase in shear strength of over 100 percent was observed for the samples suspected to heat aging. The peel strength for these samples decreased about 33 percent. The primary mode of failure in shear was scrim break within the seam (mode 7) and ply separation (mode 8) for peel. Not including chemical immersion, this seam performed satisfactorily in the other environmental conditions.

For chemical immersion, the samples were destroyed by the methylene chloride. Exposure to hydrochloric acid and methyl ethyl ketone produced a slight increase in shear coupled with a slight reduction in peel. Exposure to the other chemicals produced a reduction in both shear and peel. The primary mode of failure in shear was scrim delamination (mode 5) as compared to mode 7 for the unaged materials. The mode of failure in peel for samples exposed to phenol, sodium hydroxide and furfural was a planar failure (mode 4) in combination with ply separation (mode 8).

Sample 9, 38 mil EIA(S) - Thermal Hot Air Factory Seam

Test results are summarized in Figures 45 and 46, and table 9 in the Appendix. Except for exposure to some chemicals, this seam generally performed satisfactorily with very little change occurring to the shear strength. Of the supported materials evaluated in the study, this seam exhibited the highest shear strength. Samples exposed to heat aging and freeze/thaw cycling exhibited about a 20 percent decrease in peel. The mode of failure in peel was primarily ply adhesion (mode 8), and mode of failure in shear was in the parent material (modes 2 and/or 6).

For chemical immersion, the samples were destroyed by the methylene chloride. The samples exposed to methyl ethyl ketone and furfural were intact after 6 months of immersion, but were completely destroyed at 12 months. Severe surface peeling occurred as shown in Figures 58, 59, 79, and 80. These results indicate that the 120-day immersion period specified in EPA Test Method 9090, "Compatibility Test For Waste and Membrane Liner" may not be of long enough duration to determine the chemical compatibility of some FML seams.

For the other chemicals, no adverse effect was observed for the samples exposed to the hydrochloric acid. There was, however, some loss in seam strength for the samples exposed to phenol and sodium hydroxide.

Sample 10, 30 mil EPDM(S) - Vulcanized Factory Seam

Test results are summarized in Figures 47 and 48, and table 10 in the Appendix. This seam performed satisfactorily in all exposures except sodium hydroxide. Exposure to this chemical produced about a 60 percent reduction in shear strength. The primary mode of failure in shear was scrim break within the seam (mode 7), and ply adhesion (mode 8) for peel.

Sample 11, 30 mil CPE(U) - Solvent Adhesive Factory Seam

Test results are summarized in Figures 49 and 50, and table 11 in the Appendix. A significant decrease in peel strength of over 65 percent occurred to the seam samples subjecbed to water immersion. The failure occurred with the adhesive seam (mode 3) as compared to failure in the parent material (modes 2 and 6) for the unaged material. Samples subjected to freeze/thaw cycling also experienced a decrease in peel strength. The loss was approximately 30 percent.

This material performed poorly in the dead load peel test with all samples failing. Their failures were primarily due to a weakness in the parent material rather than the seam.

For chemical immersion, the samples were destroyed by the methylene chloride. The other chemicals, except for hydrochloric acid, had an adverse effect to varying degrees on this sample.

Sample 12, 30 mil CPE(U) - Thermal Dielectric Factory Seam

Test results are summarized in Figures 51 and 52, and table 12 in the Appendix. The performance of this seam paralleled that of sample 11 except that failure for both shear and peel generally occurred at the seam edge (mode 2) for both unaged and exposed samples.

Sample 13, 30 mil LLDPE(U) - Thermal Hot Wedge Factory Seam

Test results are summarized in Figures 53 and 54, and table 13 in the Appendix. This seam performed satisfactorily with very little change occurring to either the shear or peel strength. Failures that occurred were either in the parent material (mode 6) or at the seam edge (mode 2).

Sample 14, 30 mil PVC(U) - Solvent Adhesive Factory Seam

Test results are summarized in Figures 55 and 56, and table 14 in the Appendix. Except for exposure to some chemicals, this seam performed satisfactorily with very little change occurring to the shear strength. Exposure to 50 °C brine and heat aging produced about a 30 percent increase in peel strength. The failure in shear was primarily at the seam edge (mode 2), while failure in peel occurred within the seam (mode 3 or 4).

For chemical immersion, the samples were destroyed by the methylene chloride. The samples exposed to sodium hydroxide showed a substantial increase in shear strength due to stiffening of the material caused by plasticizer loss. Samples exposed to phenol, methyl, ethyl ketone, and furfural exhibited substantial increases in peel strength. Also, exposure to methyl ethyl ketone caused some cracking of the material as shown in Figure 48 in the Appendix. No adverse reaction was observed for samples exposed to hydrochloric acid.

Sample 15, 30 mil PVC(U) - Thermal Dielectric Factory Seam

Test results are summarized in Figures 57 and 58, and table 15 in the Appendix. Except for exposure to some chemicals, this seam performed satisfactorily with very little change occurring to either the shear or peel strengths. Failure occurred at the seam edge (mode 2) in both tests.

For chemical immersion, the performance was similar to that observed for sample 14, except that a decrease in peel strength rather than an increase occurred to the samples exposed to methyl ethyl ketone.

Comparison of the performance of samples 14 and 15 in water is shown in Figure 125.

Sample 16, 30 mil PVC/CPE(U) - Thermal Dielectric Factory Seam

Test results are summarized in Figures 59 and 60, and table 16 in the Appendix. This composite material performed similarly to the CPE seam (sample 12), except for the exposures conducted at elevated temperatures, i.e., heat aging and brine at 50 °C. A significant decrease occurred in both shear and peel strengths after exposure to these two conditions. As with sample 12, this material failed in all the dead load peel tests.

Sample 17, 36 mil CPE(S) - Bodied Solvent Adhesive Field Seam

Test results are summarized in Figures 61 and 62, and table 17 in the Appendix. As with the companion factory seam, sample 1, a significant decrease of over 50 percent occurred to the shear strength within the first 3 months of water immersion. However, very little change occurred to this property after the initial loss. There was also a decrease in the peel strength properties but not to the same degree as noted for the shear. The failure in shear was primarily scrim break within the seam (mode 7). The failure in peel for the exposed samples was also mode 7 as compared to failure in the parent material (mode 6) for the unaged materials.

For chemical immersion, the performance was similar to that for sample 1.

Sample 18, 36 mil CPE(S) - Solvent Adhesive Field Seam

Test results are summarized in Figures 63 and 64, and table 18 in the Appendix. Except for chemical immersion and exposure at elevated temperatures, this seam performed satisfactorily. After 12 months of brine exposure at 50 °C, the peel strength had decreased by 86 percent, while there was a minimal change in shear strength. There was also a decrease in peel strength of about 35 percent for samples subjected to heat aging. Again, there was minimal change in shear strength. Samples from these two exposure conditions also failed in the dead load peel test. The failure in shear was primarily scrim break within the seam (mode 7), while failure within the adhesive system (mode 3) was the most predominant in peel.

For chemical immersion, the samples were completely destroyed by the methylene chloride. All the other chemicals had an adverse effect on this seam especially in regard to peel strength properties.

Sample 19, 30 mil CSPE(S) - Bodied Solvent Adhesive Field Seam

Test results are summarized in Figures 65 and 66, and table 19 in the Appendix. Except for chemical immersion and exposure at elevated temperatures, this seam performed satisfactorily with minimal changes occurring to the seam strength properties. For samples exposed to conditions involving elevated temperatures, there was approximately a 25 percent increase in shear strength coupled with about a 25 percent decrease in peel strength. The failure in shear was primarily scrim break within the seam (mode 7). For peel, the failure was ply separation (mode 8) for the unaged materials and samples exposed to elevated temperatures. For the other exposure conditions, scrim break within the seam (mode 7) was the most predominant.

For chemical immersion, the samples were completely destroyed by the methylene chloride. Exposure to phenol, hydrochloric acid and methyl

ethyl ketone produced no adverse effect on the seam properties. Samples exposed to furfural exhibited about a 50 percent loss in peel strength coupled with a minimum increase in shear strength. Exposure to sodium hydroxide produced about a 40 percent reduction in shear.

Sample 20, 36 mil CSPE(S) - Bodied Solvent Adhesive Field Seam

Test results are summarized in Figures 67 and 68, and table 20 in the Appendix. The performance of this seam was very similar to that of the companion factory seam, sample 4. However, the peel strength of the unaged field seam was about one-half of that obtained for the unaged factory seam. The shear strengths, however, were nearly the same.

Sample 21, 36 mil CSPE(S) - Adhesive Field Seam

Test results are summarized in Figures 69 and 70, and table 21 in the Appendix. Except for chemical immersion and exposure to heat aging, this seam performed satisfactorily. For samples exposed to heat aging, there was a substantial increase of about 175 percent in the shear strength, while the peel strength remained essentially unchanged. The failure for shear was primarily scrim break within the seam (mode 7), and ply separation (mode 8) for peel.

For chemical immersion, the sample were completely destroyed by the methylene chloride. Exposure to sodium hydroxide produced about an 80 percent reduction in shear strength coupled with about a 30 percent reduction in peel. Some loss in shear strength was also observed for samples exposed to phenol. Exposure to hydrochloric acid caused some stiffening of the seam as indicated by about an 87 percent increase in shear. There was, however, only a minimal change in peel strength. No adverse effect was observed for the samples exposed to methyl ethyl ketone or furfural.

Sample 22, 36 mil CSPE)S) - Bodied Solvent Adhesive Field Seam

Test results are summarized in Figures 71 and 72, and table 22 in the Appendix. Except for chemical immersion, this seam performed satisfactorily. The primary mode of failure in both shear and peel was scrim break within the scrim (mode 7).

For chemical immersion, the samples were destroyed by the methylene chloride. Exposure to sodium hydroxide produced about a 78 percent reduction in shear strength, and minimum change in peel strength. Exposure to phenol and furfural produced an adverse effect on both shear and peel strength properties. Also, the mode of failure change to scrim delamination (mode 5). No adverse effect was observed for the samples exposed to methyl ketone and hydrochloric acid.

Sample 23, 36 mil CSPE(S) - Solvent Adhesive Field Seam

Test results are summarized in Figures 73 and 74, and table 23 in the Appendix. Except for chemical immersion and exposure to heat aging and freeze/thaw cycling, this seam performed satisfactorily. For samples exposed to heat aging, there was about a 38 percent increase in shear strength coupled with a 23 percent reduction in peel strength. Freeze/thaw cycling produced about a 40 percent reduction in shear strength and minimum effect on peel strength.

For chemical immersion, the samples were completely destroyed by the methylene chloride. Exposure to sodium hydroxide, produced about an 80 percent reduction in shear strength coupled with about a 22 percent decrease in peel strength. Exposure to phenol and furfural also produced a reduction in shear strength while the peel strength remained essentially unchanged. No adverse effect was observed for samples exposed to hydrochloric acid.

Sample 24, 36 mil CSPE(S) - Solvent Adhesive Field Seam

Test results are summarized in Figures 75 and 76, and table 24 in the Appendix. The performance of this seam was similar to that of sample 23 especially in regard to chemical immersion and the effect of heat aging and freeze/thawing cycling. Consequently, the same conclusions would apply.

Sample 25, 36 mil CSPE(S) - Solvent Adhesive Field Seam

Test results are summarized in Figures 77 and 78, and table 25 in the Appendix. The performance of this seam was also similar to that of samples 23 and 24 except that a substantial increase of over 60 percent in shear strength was observed for the samples exposed to 50 °C brine. Consequently, this material would be questionable for application involving elevated temperatures.

Sample 26, 38 mil EIA(S) - Thermal/Hot Air Field Seam

Test results are summarized in Figures 79 and 80, and table 26 in the Appendix. The performance of this seam generally paralleled that of the companion factory seam, sample 9.

Sample 27, 30 mil EPDM(S) - Gumtape/Cement Field Seam

Test results are summarized in Figures 81 and 82, and table 27 in the Appendix. Of all the seams evaluated in the study, this seam system had the lowest peel strength, 8.6 lbf/in width. As a result, all samples failed in the dead load peel test. The failures occurred within the adhesive system (mode 3). Consequently, the use of this seam would be questionable for applications where the FML might be subjected to peel forces such as wind and wave action.

Sample 28, 30 mil C PE(U) - Solvent Adhesive Field Seam

Test results are summarized in Figures 83 and 84, and table 28 in the Appendix. As with the companion factory seam, sample 11, a significant decrease in peel strength occurred to seam samples subjected to water immersion. The strength loss was about 65 percent, and the failures occurred within the adhesive seam (mode 3). Samples subjected to wet/dry cycling also experienced a decrease in peel strength. The loss was approximately 43 percent.

This material performed poorly in the dead load peel test with all samples, except those exposed to sodium hydroxide, failing.

For chemical immersion, the samples were destroyed by the methylene chloride. The other chemicals, except for hydrochloric acid, had an adverse effect to varying degrees on this sample.

Sample 29, 30 mil CPE(U) - Solvent Adhesive Field Seam

Test results are summarized in Figures 85 and 86, and table 29 in the Appendix. The performance of this seam was very similar to that of sample 28.

Sample 30, 30 mil HDPE(U) - Extrusion Fillet Weld Field Seam

Test results are summarized in Figures 87 and 88, and table 30 in the Appendix. This seam performed satisfactorily in all exposure conditions with very little change occurring to either the shear or peel strengths.

Failure in shear generally occurred within the parent material (mode 6), while failure at the seam edge (mode 2) was the most predominant in peel.

Sample 31, 80 mil HDPE(U) - Extrusion Fillet Weld Field Seam

Test results are summarized in Figures 89 and 90, and table 31 in the Appendix. This seam performed satisfactorily in all exposure conditions. A slight increase in both shear and peel strength was observed. The primary mode of failure in both tests occurred at the seam edge (mode 2).

Sample 32, 80 mil HDPE(U) - Extrusion Lap Weld Field Seam

Test results are summarized in Figures 91 and 92, and table 32 in the Appendix. For the most part, this seam performed satisfactorily. There was, however, about a 30 percent reduction in peel strength for samples subjected to freeze/thaw cycling. A partial planar failure (mode 4) occurred in these peel tests as compared to failure at the seam edge (mode 2) for the unaged material. Consequently, some additional testing should be conducted to determine the long term effect of freeze/thaw cycling on this type of field seam.

Sample 33, 80 mil HDPE(U) - Thermal Hot Dual Wedge Field Seam

Test results are summarized in Figures 93 and 94, and table 33 in the Appendix. This seam performed satisfactorily in all exposure conditions. Some increase occurred to the peel strength after all chemical exposures. The primary mode of failure in peel was at the seam edge (mode 2) as compared to planar failure within the seam (mode 4) for the unaged material.

Sample 34, 30 mil LLDPE(U) - Thermal Hot Wedge Field Seam

Test results are summarized in Figures 95 and 96, and table 34 in the Appendix. Except for chemical immersion, this seam experienced over a 50 percent decrease in its peel strength. The mode of failure was planar failure within the seam (mode 4) for the unaged material. Consequently, the performance of this seam is questionable and additional testing should be conducted on other field seams of this type to determine its suitability for seepage control applications.

For chemical immersion, there was very little change in peel strength exxcept for samples exposed to furfural. The primary mode of failure in peel was failure at seam edge (mode 2).

Sample 35, 30 mil PVC(U) - Solvent Adhesive Field Seam

Test results are summarized in Figures 97 and 98, and table 35 in the Appendix. Except for chemical immersion, this seam performed satisfactorily. The mode of failure in shear was at the seam edge (mode 2), while failure within the adhesive system (mode 3) was predominant in the peel tests.

For chemical immersion, the samples were destroyed by the methylene chloride exposure to the other chemicals, except hydrochloric acid, produced considerable stiffening of the materials. Also, some blistering was observed for samples exposed to phenol and furfural. No adverse effect was observed for samples exposed to hydrochloric acid.

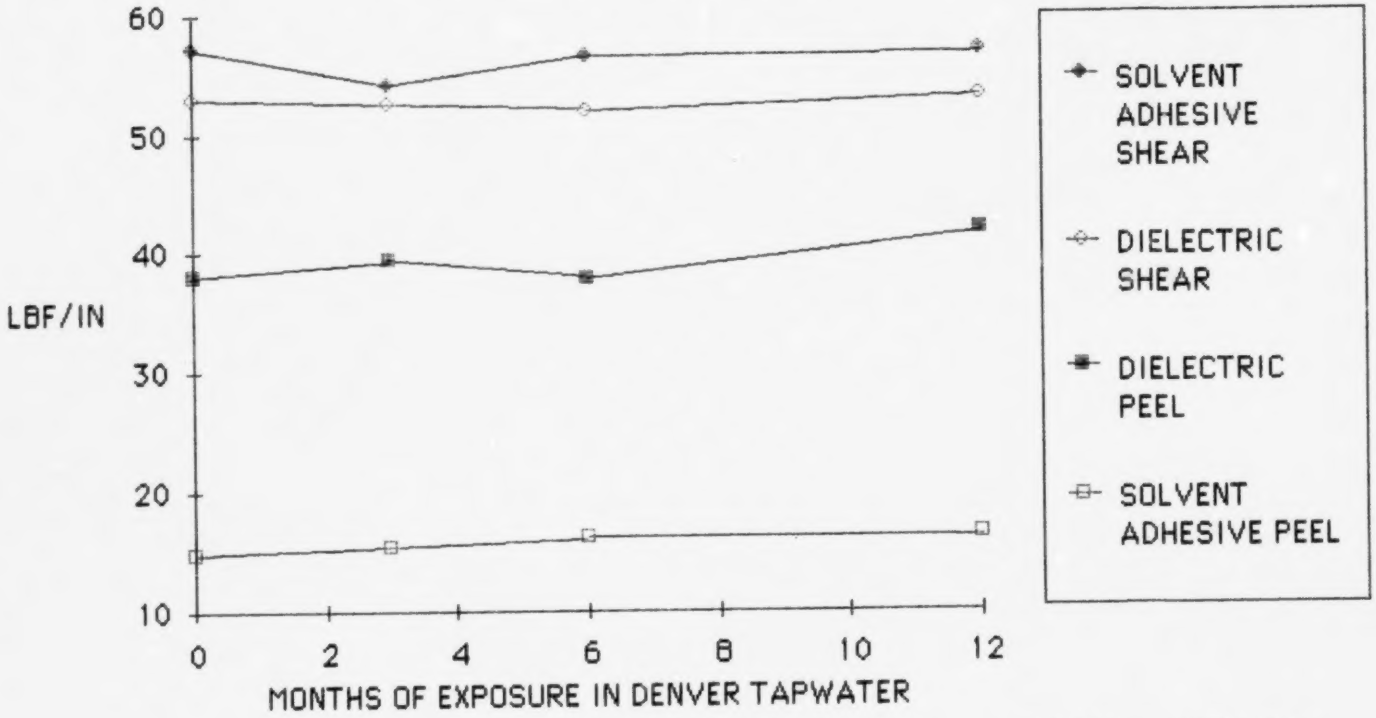
Sample 36, 30 mil PVC(U) - Solvent Adhesive Field Seam

Test results are summarized in Figures 99 and 100, and table 36 in the Appendix. Performance of this seam was very similar to that of sample 35.

Sample 37, 30 mil PVC(U) - Solvent Adhesive Field Seam

Test results are summarized in Figures 101 and 102, and table 37 in the Appendix. Of the three PVC field seams, evaluated in the study, this seam exhibited the highest peel strengths. However, the performance was very similar to that of the other two field seams, samples 35 and 36.

Figure 125. COMPARISON OF FACTORY SEAMING METHODS FOR PVC



1.0 lbf/in = 175.1 N/m

REFERENCES

1. Cope, F. G. Karpinski, J. Pacey and L. Steiner, Use of Liners for Containment at Hazardous Waste Landfills, Pollution Engineering, pp. 22-32, March 1984.

2. Otte, D. A., and R. K. Anderson, Implementation of the Minimum Technology Requirements of RCRA, as amended, Geotechnical Fabrics Report, pp. 24-27, March/April 1985.

3. Mitchell, D. H., and G. E. Spanner, Field Performance Assessment of Synthetic Liners for Uranium Tailings Pond: A Status Report, Report No. PNL-5005, Pacific Northwest Laboratory, Battelle Memorial Institute, 60 pp., March 1984.

4. NSF (National Sanitation Foundation) Standard No. 54, Flexible Membrane Liners, November 1983. Revised November 1985.

5. WPRS (Water and Power Resource Services), Reservoir Linings for Seepage and Pollution Control - Literature Search, Catalog No. 600907, U.S. Bureau of Reclamation, Denver, Colorado, September 1980.

6. Kays, W. B., Construction of Linings for Reservoirs, Tanks, and Pollutions Control Facilities, Wiley Interscience - John Wiley and Sons, 379 pp., 1977.

7. Morrison, W. R., E. W. Gray, Jr., D. B. Paul, and R. K. Frobel, Installation of Flexible Membrane Lining in Mt. Elbert Forebay Reservoir, REC-ERC-82-2, U.S. Bureau of Reclamation, Denver, Colorado, 46 pp., September 1981.

8. Giroud, J. P., and J. S. Goldstein, Geomembrane Liner Design, Waste Age, pp. 27-30, September 1982.

9. EPA, Lining of Waste Impoundment and Disposal Facilities, SW-870, Office of Solid Waste and Emergency Response, Washington, D.C., 488 pp., March 1983.

10. Fisher, G. E. Selecting and Specifying Liner Membranes, Paper presented at Corrosion/76, Houston, Texas, March 22-26, 1976.

11. Woodley, R. M., Membrane Pond Liner Applications, Included in the proceedings of the 6th Annual Industrial Pollution Conference, St. Louis, MO, Water & Wastewater Equipment Manufacturing Association, Inc., McLean, VA, pp. 113-123, April 10-13, 1978.

12. Hatheway, A. W., Membrane Liners: Types to Uses, Paper presented at the University of Kansas 32nd Annual Geotechnical Conference, March 4, 1983.

13. Small, D. A., Establishing Installation Parameters for Rubber Liner Membranes, In the Role of Rubber in Water Conservation and Pollution Control, A symposium presented at the 117th Meeting of the Rubber Division, ACS, Las Vegas, Nevada, pp. VII-1 to VIII-46, May 22, 1980.

14. Schultz, D. W., Field Studies of Geomembrane Installation Techniques, EPA-600/D-84-122, Southwest Research Institute, San Antonio, Texas, 11 pp., May 1984.

15. Strong, A. G., The Deterioration of Rubber and Plastic Linings on Outdoor Exposure: Factors Influencing Their Longevity, In: The Role of Rubber in Water Conservation and Pollution Control, A symposium presented at the 117th Meeting of the Rubber Division, ACS, Las Vegas, Nevada, pp. IV-1 to IV-46, May 22, 1980.

16. Gunkel, R. C., Membrane Liner Systems for Hazardous Waste Landfills, In: Disposal of Hazardous Wastes Proceedings of the Seventh Annual Research Symposium, EPA - 600/9/81 - 0026, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 131-167, March 1981.

17. Morrison, W. R., and J. G. Starbuck, Performance of Plastic Canal Linings, REC-ERC-84-1, U.S. Bureau of Reclamation, Denver, Colorado, 114 pp., January 1984.

18. Haxo, H. E. Jr. et al., Liner Material Exposed to Hazardous and Toxic Waste, EPA/600/2-84/169, U.S. Environmental Protection Agency, Cincinnati, Ohio, 271 pp., September 1984.

19. Nelson, N. A., H. E. Haxo Jr., and P. McGlew, Recovery and Testing of a Synthetic Liner From a Waste Lagoon After Long-Term Exposure In: Land Disposal of Hazardous Waste, Proceedings of the Eleventh Annual Research Symposium, EPA/600/9-85/013, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 296-306, April 1985.

20. Mitchell, D. H, Technology for Uranium Mill Pond, Using Geomembrane, Report No. PNL-5164, Pacific Northwest Laboratory, Battelle Memorial Institute, 76 pp., December 1984.

21. EMCON Associates, Field Verification of Liners from Sanitary Landfills, EPA/600/2-83/046, U.S. Environmental Protection Agency, Cincinnati, Ohio, 31 pp., June 1982.

22. Stryon, C. R., III., Z. B. Fry. Jr., and G. L. Carr, Effect of Flue Gas Cleaning Sludges on Selected Liner Materials, EPA 600/2-81-098, U.S. Environmental Protection Agency, Cincinnati, Ohio, 96 pp., June 1981.

23. Frobel, R. K., Methods of Constructing and Evaluating Geomembrane Seams, In: Proceeding of International Conference on Geomembranes, Denver, Colorado, vol. II, pp. 359-364, June 20-24, 1984.

24. Seaman, R., The Evaluation of Seam Quality in Geomembrane Systems, In: Proceedings of International Conference on Geomembranes, Denver, Colorado, vol. II, pp. 365-367, June 20-24, 1984.

25. Spanner, G. E., Nondestructive technique for Assessing Film Seam Quality of Prefabricated Geomembranes, In: Proceedings of International Conference on Geomembranes, Denver, Colorado, vol. II, pp. 369-373, June 20-24, 1984.

26. Price J. M., Extrusion Welding of High Density Polyethylene Geomembranes, In: Proceedings of International Conference on Geomembranes, Denver, Colorado, vol. II, pp. 375-377, June 20-24, 1984.

27. Peggs, I. D., Why Quality Control? A Graphic Case History, In: Proceedings of Geotechnical '85 Fabrics Conference, Cincinnati, Ohio, pp. 35-43, June 4-5, 1985.

28. Peggs, I.D., and D. Little, The Effectiveness of Peel and Shear Tests in Evaluating HDPE Geomembrane Seams, In: Proceedings of Second Canadian Symposium on Geotextiles and Geomembranes, Edmonton, Alberta, Canada, pp. 141-146, September 23-24, 1985.

29. Peggs, I. D., and R. Briggs and D. Little, Development in Ultrasonics for Geomembrane Seam Inspection, In: Proceedings of Second Canadian Symposium on Geotextiles and Geomembranes, Edmonton, Alberta, Canada, pp. 153-156, September 23-24, 1985.

30. Jasinkski, R., Spec'ing A Liner? Waste Age, pp. 62, 64-65, May 1985.

APPENDIX

SEAM AND PEEL STRENGTH TEST RESULTS

Tables 1 through 37

CHEMICAL IMMERSION PHOTOGRAPHS

Figures 1 through 80

TABLE 1. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CPE (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 1

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	78.4	3.5	7	59.8	3.8	7
WATER 3	27.5	1.0	5	37.6	3.3	5
WATER 6	27.4	1.6	7	29.6	1.8	7
WATER 12	32.2	2.9	7	48.7	5.4	7
23° BRINE 3	33.9	0.6	5	34.2	3.3	5
23° BRINE 12	34.5	1.6	7	33.9	1.9	7
50° BRINE 3	96.7	2.7	7	44.6	2.6	7
50° BRINE 6	41.0	4.1	7	41.4	4.8	7
50° BRINE 12	82.7	6.4	7	40.9	3.4	7
PHENOL 3	7.4	21.5	5	8.2	0.9	4-5
PHENOL 6	3.4	0.8	7	5.4	0.5	7
PHENOL 12	12.1	10.2	5	11.2	1.0	5
HCL 3	36.5	1.7	7	36.0	2.1	5
HCL 6	35.6	0.4	7	32.9	4.3	7
HCL 12	40.2	1.7	5	47.7	2.6	5
NAOH 3	22.5	7.9	7	35.8	1.6	7
NAOH 6	16.1	1.9	7	17.6	1.8	7
NAOH 12	10.1	0.9	7-1	8.5	1.2	4
MEK 3	31.4	1.7	7	33.8	6.3	7
MEK 6	24.9	1.3	7	25.3	1.6	7
MEK 12	51.1	3.4	5	44.1	2.2	5
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	26.8	0.5	7	30.8	3.6	7
FURFURAL 6	25.4	1.8	5	24.8	5.1	5
FURFURAL 12	29.8	2.2	5	30.0	1.4	5
H A 4	82.0	6.0	7	45.1	9.4	5
H A 8	86.3	4.0	7	56.0	1.1	2-7
H A 13	88.4	2.6	7	53.4	4.8	7-5
F/T 10	29.5	2.0	7	40.2	3.0	7
F/T 20	29.1	2.8	7	31.7	5.7	7
F/T 50	18.9	3.3	7	29.7	6.4	7
W/D 10	31.3	1.9	7	33.8	3.8	7
W/D 20	33.3	3.3	7	35.5	2.5	7
W/D 50	44.0	1.3	7	44.3	2.8	7
EMMAQUA				38.5	13.8	7-4

* 1.0 lbf/in = 175.1 N/m

TABLE 2. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CPE (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 2

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	123.4	1.5	7	16.2	1.1	4
WATER 3	158.0	5.1	7	17.3	0.5	4
WATER 6	142.4	18.4	7	17.0	2.4	4
WATER 12	152.8	3.6	7	13.0	0.2	4
23° BRINE 3	153.4	4.1	7	17.8	0.4	4
23° BRINE 12	150.3	6.9	7	30.3	7.3	4
50° BRINE 3	150.4	8.4	7	16.8	2.1	4
50° BRINE 6	147.4	4.5	7	17.6	4.1	4
50° BRINE 12	158.0	5.7	1	19.3	4.8	4
PHENOL 3	61.0	4.8	5-1	7.5	0.6	4
PHENOL 6	39.5	11.0	7	6.7	0.7	4
PHENOL 12	79.4	3.0	5	14.2	1.3	4
HCL 3	150.0	0.0	9	20.2	1.1	4
HCL 6	147.6	4.9	7	22.6	0.3	4
HCL 12	170.9	3.9	7	21.1	1.4	4
NAOH 3	143.5	8.8	1-2	26.6	0.6	4
NAOH 6	81.4	5.0	7	24.7/8.1	3.4/1.3	8-4
NAOH 12	63.9	2.0	7	14.6/8.6	0.7/0.9	8-4
MEK 3	140.5	16.4	7	12.4	1.9	4
MEK 6	137.5	2.9	7	23.1	6.3	4-7-8
MEK 12	109.9	23.9	5	14.0	1.4	4
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	124.5	13.4	5	25.8/10.5	2.2/2.7	8
FURFURAL 6	111.7	6.5	5	25.0/12.5	3.9/4.6	8
FURFURAL 12	115.1	18.9	5	20.5	1.9	4
H A 4	151.0	4.2	1-6-7	19.8	2.5	4
H A 8	151.9	9.9	7	17.8	1.1	4
H A 13	139.1	3.3	7-2-1	17.7	0.9	4
F/T 10	146.0	3.1	7	14.4	1.1	4
F/T 20	139.0	4.0	7	16.8	5.5	4
F/T 50	142.9	10.1	7	13.2	0.5	4
W/D 10	149.2	2.2	7	14.1	1.3	4
W/D 20	150.3	5.4	7	15.2	0.4	4
W/D 50	138.2	0.8	7-1-6	22.9	3.0	4
EMMAQUA				26.8/18.3	9.0	4-8

* 1.0 lbf/in = 175.1 N/m

TABLE 3. SEAM SHEAR AND PEEL STRENGTH - 30 MIL CSPE (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 3

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	31.0	1.0	7	29.6	1.1	2
WATER 3	32.8	1.0	7	29.9	2.1	6-7
WATER 6	31.7	0.8	7	29.6	1.7	4-6
WATER 12	32.0	1.7	7	29.3	1.3	4-7
23° BRINE 3	32.6	1.0	7	29.6	0.9	6-7
23° BRINE 12	33.3	1.2	7	26.8	2.7	7
50° BRINE 3	33.3	1.4	7	30.4	3.3	4
50° BRINE 6	32.1	0.9	7	27.3	0.4	4
50° BRINE 12	36.3	0.9	7	26.0/18.6	1.8/1.3	7-8
PHENOL 3	24.7	1.1	7	24.0	0.4	5
PHENOL 6	20.6	3.6	7	22.5	1.3	7
PHENOL 12	24.9	1.1	7	22.2	1.6	7
HCL 3	31.1	0.4	7	29.9	1.8	5
HCL 6	31.1	1.7	7	28.3	0.7	7
HCL 12	30.7	0.7	7	28.4	1.5	7
NAOH 3	24.8	2.1	5	27.0	2.3	5
NAOH 6	19.3	6.1	7	26.7	2.9	7
NAOH 12	19.2	4.5	7	23.0	2.4	7
MEK 3	32.0	0.9	7	24.9	7.4	7-4
MEK 6	31.7	0.7	7	29.2	1.0	7
MEK 12	36.1	0.4	7	23.8	0.9	4
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	34.8	1.9	7	31.1	2.4	7
FURFURAL 6	32.0	1.1	7	28.6	0.9	7
FURFURAL 12	33.6	0.5	7	28.6	2.3	5
H A 4	34.6	0.8	7	24.7/14.9	2.0/0.8	8
H A 8	33.8	1.2	7	23.7/14.1	1.4/0.8	4-8
H A 13	38.8	6.2	7	19.9/13.3	1.1/0.9	4-8
F/T 10	31.6	1.4	7	28.4	2.1	4-7
F/T 20	28.9	0.7	7	28.6	1.7	7
F/T 50	30.7	1.9	7	29.1	2.7	7
W/D 10	30.7	0.4	7	26.6	2.0	7
W/D 20	30.3	0.6	7	26.9	2.0	7
W/D 50	30.1	1.2	7	27.7	1.3	7
EMMAQUA				—	—	—

* 1.0 lbf/in = 175.1 N/m

TABLE 4. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 4

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	63.8	1.4	7	61.1	2.8	7
WATER 3	42.7	1.2	7	52.8	5.7	6
WATER 6	43.0	1.6	7	53.4	3.0	4-5
WATER 12	49.9	1.3	5	40.4	4.0	7
23° BRINE 3	41.4	1.3	7	42.3	3.0	4-6
23° BRINE 12	41.5	1.0	7	34.3/19.6	1.5/1.0	8-4
50° BRINE 3	52.8	2.5	7	6.6	0.4	4
50° BRINE 6	51.2	2.0	7	9.5	0.6	4
50° BRINE 12	87.5	1.9	7	2.3	0.2	4
PHENOL 3	24.9	3.8	5-6	12.8	4.7	4
PHENOL 6	21.1	0.7	7	23.8/22.9	1.7/0.8	8
PHENOL 12	19.9	0.6	5	21.3	1.7	4
HCL 3	50.5	0.4	7	51.7	3.7	4
HCL 6	51.1	0.8	7	56.3	6.0	6-7
HCL 12	58.2	4.3	5	54.5	2.7	4
NAOH 3	35.0	1.2	7	36.4	3.6	4
NAOH 6	35.8	1.5	5	35.8	3.2	5
NAOH 12	36.9	12.3	5	34.9	10.0	5-6
MEK 3	45.3	2.9	5	47.7	5.9	7
MEK 6	44.5	1.4	5	38.4	1.6	6-5
MEK 12	43.2	3.3	5	41.4	3.3	4-5
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	46.8	5.1	7	20.6	9.7	4
FURFURAL 6	36.1	6.8	5	40.5	2.5	5-7
FURFURAL 12	42.0	0.9	5	32.3	3.2	5
H A 4	85.5	5.1	7	4.2	0.3	4
H A 8	92.3	1.8	7	2.5	0.0	4
H A 13	96.2	4.2	7	2.9	0.2	4
F/T 10	46.3	3.3	7	44.2	14.8	4-6
F/T 20	46.0	1.2	7	35.8	9.3	4-5
F/T 50	43.5	1.5	7	45.9	3.2	5
W/D 10	36.7	1.2	7	16.8	3.9	4
W/D 20	43.3	1.3	7	48.9	8.3	7
W/D 50	44.2	1.8	5	41.5	3.0	4
EMMAQUA				—	—	—

* 1.0 lbf/in = 175.1 N/m

TABLE 5. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 5

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	79.9	2.8	7	33.6/15.1	2.6/0.7	8
WATER 3	65.9	1.9	7	30.6/21.1	1.9/1.3	8
WATER 6	62.7	2.7	7	31.2/17.0	3.4/2.2	8
WATER 12	74.3	6.3	7	31.5/15.3	3.3/1.5	8
23° BRINE 3	64.5	1.8	7	29.9/22.8	0.8/1.4	8
23° BRINE 12	69.1	2.2	7	29.7/16.4	2.5/1.3	8
50° BRINE 3	68.4	3.8	7	29.9/18.3	2.2/4.9	8
50° BRINE 6	124.2	22.1	7	27.8/14.8	3.6/1.7	8
50° BRINE 12	154.2	11.2	7	25.1/14.0	3.0/0.8	8
PHENOL 3	32.8	0.9	5	35.4/12.8	3.3/0.8	8
PHENOL 6	19.3	2.7	7	22.0/15.0	1.4/3.7	8
PHENOL 12	35.3	1.6	5	41.0	1.2	8
HCL 3	139.0	4.8	7	36.4	6.2	4
HCL 6	141.8	5.9	7	26.0/16.3	2.9/1.1	8
HCL 12	146.2	3.6	5	37.4/17.6	4.3/3.6	8
NAOH 3	42.0	1.3	7	31.6/11.8	1.2/1.1	8
NAOH 6	34.7	7.9	5	36.1/16.4	3.8/4.3	8
NAOH 12	33.0	11.6	5	31.5	6.0	4-5
MEK 3	57.2	2.1	7	27.0	3.9	4
MEK 6	47.7	0.8	7	31.9/18.0	5.4/2.9	8
MEK 12	54.5	6.5	5	32.9/14.7	1.9/1.4	8
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	71.5	0.9	5	29.9/15.5	2.7/1.4	8
FURFURAL 6	65.5	3.4	5	35.1/16.4	6.0/2.4	8
FURFURAL 12	54.0	3.6	5	35.1/17.6	2.3/2.8	8
H A 4	160.1	7.7	7	23.9/13.1	1.7/1.0	8
H A 8	161.9	5.6	7	24.8/12.4	1.5/0.9	8
H A 13	165.7	5.5	7	21.5/12.1	0.7/0.2	8
F/T 10	67.1	8.8	7	31.4/17.5	3.0/1.9	8
F/T 20	57.5	3.1	7	31.8/20.1	2.1/4.5	8
F/T 50	57.1	4.4	7	27.4/19.0	2.8/1.8	8
W/D 10	63.7	11.5	7	27.7/17.8	2.5/2.4	8
W/D 20	77.0	7.7	7	34.0/23.0	4.3/1.8	8
W/D 50	74.1	10.6	7	32.9/15.2	1.5/1.1	8
EMMAQUA				21.5/13.1	1.0/0.4	8

* 1.0 lbf/in = 175.1 N/m

TABLE 6. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 6

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	90.4	1.5	6	48.3	3.6	7
WATER 3	46.9	2.5	5	50.3	3.6	6-7
WATER 6	43.7	5.3	7	47.2	2.7	7
WATER 12	49.6	2.5	7	52.3	2.8	7
23° BRINE 3	54.9	1.8	5	48.9	2.6	6-7
23° BRINE 12	62.2	6.7	7	53.6	2.6	7
50° BRINE 3	86.5	1.7	7	59.1	2.7	2
50° BRINE 6	81.5	3.9	7	57.0	4.4	7
50° BRINE 12	81.1	5.5	7	60.1	4.8	7
PHENOL 3	16.4	1.0	5	24.0	2.0	4
PHENOL 6	10.8	0.4	7	17.4	1.2	7
PHENOL 12	10.2	0.8	5	15.7	0.5	5
HCL 3	40.5	1.5	7	41.9	2.0	7
HCL 6	48.2	2.6	7	47.3	2.3	2
HCL 12	53.0	4.0	5	50.1	3.5	2
NAOH 3	31.7	1.1	7	39.1	1.5	7
NAOH 6	29.6	2.6	7-6	38.9	2.5	7-6
NAOH 12	34.5	13.6	5	50.0	4.2	5-6
MEK 3	45.0	2.3	7	48.9	3.1	5
MEK 6	39.9	2.3	5	45.5	3.2	2
MEK 12	38.2	2.2	5	44.7	2.4	5
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	43.5	2.7	5	48.5	5.9	7
FURFURAL 6	31.9	1.7	5	45.5	2.1	5
FURFURAL 12	25.7	2.4	5	30.3	1.6	5
H A 4	87.9	2.1	1-2-6	40.1	4.7	5
H A 8	86.1	2.2	7	34.0	4.6	5
H A 13	88.5	6.1	2-7-1	35.8	3.2	5
F/T 10	50.0	1.7	7	52.1	4.4	7
F/T 20	49.1	2.6	7	47.3	4.3	7
F/T 50	44.6	2.4	7	49.6	4.2	7
W/D 10	51.8	3.5	7	50.2	2.4	7
W/D 20	52.8	0.5	7	54.3	3.2	7
W/D 50	57.1	2.3	7	53.5	1.8	7-6
EMMAQUA				52.6	4.9	5-7

* 1.0 lbf/in = 175.1 N/m

TABLE 7. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - SOLVENT ADHESIVE FACTORY SEAM - SAMPLE 7

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	91.8	4.1	7	34.4/17.7	0.8/0.8	8
WATER 3	90.5	5.5	7	34.7/18.7	1.2/5.0	8
WATER 6	104.6	4.2	7	33.5/15.6	0.5/0.7	8
WATER 12	104.5	3.5	7	27.2/13.1	1.1/0.3	8
23° BRINE 3	89.6	4.0	7	27.7/14.4	3.0/0.2	8
23° BRINE 12	100.8	2.4	7	30.9/16.4	4.5/0.6	8
50° BRINE 3	145.1	9.0	7	27.7/12.6	1.4/0.7	8
50° BRINE 6	129.1	12.5	7	25.5/14.0	5.5/0.9	8
50° BRINE 12	145.1	5.1	7	25.1/13.4	3.0/0.7	8-3
PHENOL 3	50.4	3.4	5	25.5/17.8	1.8/4.2	8
PHENOL 6	22.3	1.1	7	28.0/17.3	10.5/4.8	8-3
PHENOL 12	78.8	12.9	5	26.1/13.6	1.7/0.8	8
HCL 3	119.7	2.8	7	25.3	4.8	7
HCL 6	85.7	9.4	5	31.1/19.6	4.9/7.8	8
HCL 12	112.0	7.1	5	34.5/17.5	7.5/1.2	8
NAOH 3	80.3	1.3	5	29.3/16.3	3.2/0.9	8
NAOH 6	62.6	8.1	7-5	25.7/14.9	6.1/0.6	8
NAOH 12	20.6	1.3	7	19.3/10.6	0.6/0.0	3-8
MEK 3	61.3	8.6	7	30.8/14.5	1.9/2.9	8
MEK 6	114.9	7.5	5	26.6/14.0	6.8/1.8	8
MEK 12	94.3	28.8	5	26.5/14.4	3.0/0.8	8
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	121.5	11.9	7	28.9/17.0	3.8/0.9	8
FURFURAL 6	91.8	19.3	5	27.5/14.6	3.0/1.0	8
FURFURAL 12	103.6	7.8	5	26.7/14.8	2.2/0.6	8
H A 4	153.5	8.9	7	27.7/11.8	3.5/0.8	8
H A 8	156.9	6.9	7	24.4/11.6	1.0/0.3	8
H A 13	148.5	3.9	7	24.4/10.4	3.3/0.5	8-3
F/T 10	102.9	5.5	7	31.7/13.8	3.3/0.9	8
F/T 20	95.5	5.2	7	29.0/13.6	4.1/0.5	8
F/T 50	86.1	4.2	7	29.5/13.9	0.8/1.3	8
W/D 10	100.6	3.9	7	31.6/15.0	3.4/0.9	8
W/D 20	96.0	5.4	7	28.7/13.6	2.6/0.8	8
W/D 50	130.8	8.8	7	29.2/15.8	6.8/7.2	8-3
EMMAQUA				26.9/12.6	1.6/0.6	8

* 1.0 lbf/in = 175.1 N/m

TABLE 8. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - THERMAL DIELECTRIC FACTORY SEAM - SAMPLE 8

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	73.5	1.7	7	30.9/11.4	1.7/0.4	8
WATER 3	51.7	1.7	7	30.1/12.7	0.7/0.2	8
WATER 6	60.4	1.5	7	30.6/12.4	2.0/0.7	8
WATER 12	65.2	4.6	7	27.5/11.0	0.8/0.6	4-8
23° BRINE 3	54.5	2.7	7	30.5/11.4	2.3/1.9	8
23° BRINE 12	60.5	2.8	7	30.2/12.1	1.2/3.1	8
50° BRINE 3	87.7	6.1	7	29.0/10.9	1.0/0.8	4-8
50° BRINE 6	76.5	5.3	7	31.1/12.0	1.7/0.3	5-8
50° BRINE 12	102.5	4.0	7	26.0/13.8	1.6/3.9	8
PHENOL 3	28.0	2.3	5	24.4/9.2	2.6/3.1	4-8
PHENOL 6	22.7	8.1	7	16.7	1.1	4-8
PHENOL 12	54.5	6.4	5	23.3/17.9	2.4/2.1	4-8
HCL 3	70.9	3.4	8	31.9/13.4	2.0/1.3	8
HCL 6	69.6	8.1	7	27.3/11.8	1.3/4.9	8
HCL 12	86.0	6.5	5	27.8/17.1	2.0/4.2	8
NAOH 3	79.2	5.8	7	30.5/15.4	2.9/3.4	8
NAOH 6	47.6	4.0	7	30.3/16.5	3.6/1.8	8
NAOH 12	29.8	8.0	5	22.5/11.2	2.9/0.3	8-4
MEK 3	61.3	8.6	7	30.8/14.5	1.9/2.9	8
MEK 6	79.8	1.9	5	22.8	7.0	4
MEK 12	96.4	7.0	5	25.0/14.4	3.3/2.8	8
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--		--	--
FURFURAL 3	100.0	8.9	7	30.9/12.8	2.5/1.7	8
FURFURAL 6	77.4	6.9	5	28.6/11.5	2.2/7.6	8
FURFURAL 12	51.0	5.2	5	24.1/14.9	4.9/0.4	8-4
H A 4	160.0	3.9	7	18.3	1.7	4
H A 8	150.0	2.3	7	18.8/8.0	5.8/0.5	4-8
H A 13	156.3	9.9	7-6-2	20.7	4.4	4-8
F/T 10	62.1	5.6	7	30.8/13.0	2.3/2.0	6-8
F/T 20	61.0	2.8	7	28.7/10.1	1.9/1.5	8-4-5
F/T 50	56.2	6.0	7	30.2/11.4	3.1/0.6	8
W/D 10	64.5	6.0	7	27.6/10.7	3.3/2.4	8-4
W/D 20	69.9	5.9	7	26.0/11.2	1.4/0.2	8-4
W/D 50	85.8	8.8	7	26.4/9.9	4.9/0.3	4-8
EMMAQUA				21.1	3.9	4

* 1.0 lbf/in = 175.1 N/m

TABLE 9. SEAM SHEAR AND PEEL STRENGTH - 38 MIL EIA (S) - THERMAL HOT AIR FACTORY SEAM - SAMPLE 9

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	353.8	10.7	6	43.8/20.5	0.5/1.7	8
WATER 3	289.0	3.9	6	35.0/10.5	1.8/1.7	8
WATER 6	323.3	42.5	1	38.6/9.3	3.5/0.5	8
WATER 12	351.1	14.6	1-6	36.9/10.3	3.2/2.8	8
23° BRINE 3	298.0	5.1	6	23.8	3.0	4
23° BRINE 12	327.9	33.3	1-2-6	35.8/11.3	3.4/3.0	8
50° BRINE 3	358.3	23.8	6	34.7/10.7	3.6/0.5	8
50° BRINE 6	319.5	11.2	1-6-7	32.4/9.8	2.7/0.5	8
50° BRINE 12	355.3	26.0	2-1	38.9/12.5	4.7/0.6	8
PHENOL 3	120.1	26.1	3	2.3	1.4	3
PHENOL 6	150.0+	NA	9	14.4/7.4	1.4/0.3	8
PHENOL 12	251.0	99.4	6	23.1/8.4	2.1/2.1	8
HCL 3	150.0+	NA	9	41.2/11.5	4.7/0.5	7
HCL 6	150.0+	NA	9	34.5/18.3	5.1/3.9	8
HCL 12	356.3	22.8	7	33.7/13.6	3.5/1.9	8
NAOH 3	150.0+	NA	9	25.7/23.7	7.2/1.7	4-8
NAOH 6	150.0+	NA	9	28.9/12.2	5.9/3.4	8
NAOH 12	216.2	38.6	7	26.3/7.8	2.4/0.5	8
MEK 3	150.0+	NA	9	31.3/12.5	4.1/1.3	8
MEK 6	150.0+	NA	9	34.4/14.9	5.3/4.9	8
MEK 12	—	—	—	—	—	—
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	150.0+	NA	9	5.7	2.5	4
FURFURAL 6	150.0+	NA	9	31.7	5.9	4-8
FURFURAL 12	—	—	—	—	—	—
H A 4	353.2	9.4	2-6	31.6/10.8	5.9/0.3	8
H A 8	329.7	15.3	1-2	34.9/16.7	2.7/1.0	4-8
H A 13	358.9	6.4	2-6	31.8/15.7	3.7/2.4	4-8
F/T 10	362.3	17.3	1-2-6	35.5/9.9	4.4/0.5	8
F/T 20	364.1	14.6	1-6	25.7/10.1	3.7/1.4	8
F/T 50	354.7	23.1	2-6	30.9/11.5	2.1/5.1	8
W/D 10	334.0	42.3	1-2	33.5/11.3	5.8/0.5	8
W/D 20	332.9	19.9	6-2	33.5/18.0	3.8/2.0	8-4
W/D 50	355.4	7.2	2-1	33.1/12.2	4.1/1.0	8-4
EMMAQUA				40.7/12.1	1.8/0.1	8

* 1.0 lbf/in = 175.1 N/m

TABLE 10. SEAM SHEAR AND PEEL STRENGTH - 30 MIL EPDM (S) - VULCANIZED FACTORY SEAM - SAMPLE 10

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	70.2	1.4	7	36.2/21.2	2.2/0.9	8
WATER 3	71.1	3.9	7	38.9/29.5	2.2/3.2	8
WATER 6	91.9	4.5	7	39.5	4.6	5
WATER 12	82.6	2.8	7	38.2/27.5	3.0/3.1	8
23° BRINE 3	83.3	2.7	7	41.4/30.6	4.7/2.9	8
23° BRINE 12	84.9	6.3	7	36.5/19.5	10.2/6.7	5-8
50° BRINE 3	70.1	4.9	7	33.3/17.8	2.3/4.1	6-8
50° BRINE 6	71.0	2.2	7	29.8/12.2	5.4/2.0	8-4
50° BRINE 12	94.1	2.1	7	39.5/12.3	7.3/1.6	8
PHENOL 3	58.2	2.3	5	43.1/21.5	3.4/7.7	8
PHENOL 6	41.2	2.7	7	36.2/18.7	2.2/1.5	8
PHENOL 12	68.5	3.7	7	37.0	4.6	8
HCL 3	88.0	2.3	7	35.8	5.2	4
HCL 6	68.2	5.8	7	33.2/15.8	4.9/2.7	8
HCL 12	59.6	6.0	7	40.1/21.4	5.0/2.4	8
NAOH 3	67.6	10.9	7	40.9	12.5	8-4
NAOH 6	23.0	12.6	5	38.1/16.5	3.4/0.3	8
NAOH 12	27.1	16.1	7	38.6/26.1	5.7/3.0	4-5-8
MEK 3	82.0	0.9	7	38.6	4.8	4
MEK 6	54.3	2.8	5	39.0/14.9	4.2/0.9	8
MEK 12	73.8	4.2	7	42.6/12.3	4.0/0.7	8
MCL 3	111.4	2.7	7	38.8/14.1	14.7/0.6	8-4
MCL 6	98.9	7.3	7	45.6/12.3	9.4/2.0	8
MCL 12	90.6	4.1	7	38.1/14.0	5.0/0.4	8
FURFURAL 3	92.0	7.4	7	38.4/19.4	6.2/1.7	8
FURFURAL 6	80.0	3.4	5	35.3/15.3	2.7/0.9	8
FURFURAL 12	73.4	10.7	5	46.4/25.1	4.2/1.7	8
H A 4	50.3	9.0	7	43.7/16.5	7.2/1.1	8
H A 8	64.1	3.5	7	40.4/14.3	3.8/1.7	8
H A 13	79.4	7.9	7	43.6/14.0	3.9/1.9	8
F/T 10	58.4	16.1	7	31.3/16.3	4.7/1.7	4-8
F/T 20	78.0	6.4	7	42.4	5.5	5-8
F/T 50	67.2	3.2	7	47.3/29.8	6.2/2.6	8-4
W/D 10	60.7	11.3	7	29.8	4.7	7
W/D 20	59.8	3.4	7	34.3/16.8	1.1/4.9	8
W/D 50	64.0	3.1	7	46.1/23.6	2.8/6.1	8
EMMAQUA				48.0/11.7	2.8/1.1	8

* 1.0 lbf/in = 175.1 N/m

TABLE 11. SEAM SHEAR AND PEEL STRENGTH - 30 MIL CPE (U) - SOLVENT ADHESIVE FACTORY SEAM - SAMPLE 11

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	42.0	1.0	2	21.3	0.9	2-6
WATER 3	43.7	2.1	2	18.3	0.6	3
WATER 6	41.1	0.8	2-6	14.7	0.6	3
WATER 12	36.0	3.6	6	7.3	0.6	3
23° BRINE 3	42.2	1.2	2	20.4	1.0	4-6
23° BRINE 12	34.1	1.0	2	18.7	0.6	3
50° BRINE 3	34.9	5.5	2	20.0	0.8	6
50° BRINE 6	39.3	1.5	2	18.9	0.3	3-6
50° BRINE 12	37.2	1.3	2	19.0	0.6	4-6
PHENOL 3	3.4	0.1	3	0.3	NA	3
PHENOL 6	4.9	4.9	3-6	0.8	0.1	3
PHENOL 12	7.3	2.5	3	2.4	0.6	3
HCL 3	35.6	0.4	2	20.1	0.8	3
HCL 6	40.0	1.9	2	20.1	0.5	3
HCL 12	42.6	2.1	2	20.4	0.5	3
NAOH 3	44.1	1.3	2	22.7	0.8	4
NAOH 6	43.3	1.8	2-1	20.6	1.6	3
NAOH 12	41.1	3.9	2	12.1	0.8	3
MEK 3	30.4	3.2	2	19.1	1.1	6
MEK 6	34.4	0.7	2	19.3	1.0	3
MEK 12	19.2	3.5	6	18.5	1.1	3-6
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	16.7	1.8	2	3.8	0.8	3
FURFURAL 6	18.0	1.3	2	4.1	0.2	3
FURFURAL 12	14.0	1.7	1	3.8	0.3	3
H A 4	30.9	0.4	2	19.4	0.6	6
H A 8	32.3	1.4	2	19.4	0.6	3-6
H A 13	34.7	2.1	2	17.8	3.2	3-6
F/T 10	40.7	1.3	1-2-6	14.6	0.3	3
F/T 20	41.8	2.2	1-2	13.4	0.6	3
F/T 50	39.9	3.1	6-1	14.1	0.8	3
W/D 10	37.5	3.0	2	12.4	0.1	4
W/D 20	38.0	4.3	2-6	12.4	0.6	3
W/D 50	44.7	0.7	2	16.7	0.7	3
EMMAQUA				18.4	0.5	4-1

* 1.0 lbf/in = 175.1 N/m

TABLE 12. SEAM SHEAR AND PEEL STRENGTH - 30 MIL CPE (U) - THERMAL DIELECTRIC FACTORY SEAM - SAMPLE 12

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	33.1	0.9	2	29.6	1.2	2
WATER 3	29.9	0.1	2-6	21.0	2.2	2
WATER 6	29.5	0.9	2	23.0	0.8	2
WATER 12	25.8	0.9	2	19.0	1.0	2
23° BRINE 3	35.3	2.8	2	25.6	2.4	2
23° BRINE 12	28.3	2.7	2-1	27.2	1.2	2
50° BRINE 3	37.1	0.8	2	25.9	4.1	2-4-6
50° BRINE 6	33.5	0.4	2	26.8	1.1	2
50° BRINE 12	32.5	2.1	2	25.3	1.4	2
PHENOL 3	11.3	1.7	6-2	8.4	2.4	2-4
PHENOL 6	9.6	0.4	2	9.2	1.1	4
PHENOL 12	20.8	1.6	2	15.1	1.5	4
HCL 3	30.4	1.5	2	21.8	1.4	2
HCL 6	32.7	0.3	2	27.6	1.4	2
HCL 12	30.1	1.3	2	26.2	0.6	2
NAOH 3	33.2	1.5	2	25.0	2.2	4
NAOH 6	31.3	2.0	2	22.8	1.1	2
NAOH 12	31.2	1.7	2	22.5	1.3	2
MEK 3	29.0	1.8	2	20.0	0.9	2
MEK 6	26.2	3.9	2	21.8	0.6	2
MEK 12	21.2	0.9	2	20.0	0.5	2
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	15.2	2.3	2-1	9.8	1.2	4
FURFURAL 6	14.7	1.3	2	12.8	0.8	2
FURFURAL 12	16.4	0.6	2	10.7	0.9	4
H A 4	33.7	0.9	2	28.0	1.0	2
H A 8	28.6	1.4	2	25.9	0.6	2
H A 13	31.2	0.9	2	26.2	0.2	2
F/T 10	30.9	1.3	2	20.0	4.1	4-6
F/T 20	32.7	1.1	2	25.4	0.9	2
F/T 50	30.2	1.6	2	24.6	3.5	2
W/D 10	28.5	0.8	2	18.9	5.0	2-4
W/D 20	24.8	2.1	2	20.5	0.5	2
W/D 50	33.4	2.7	2	23.3	1.5	2
EMMAQUA				24.2	3.3	6-4-1

* 1.0 lbf/in = 175.1 N/m

TABLE 13. SEAM SHEAR AND PEEL STRENGTH - 30 MIL LLDPE (U) - THERMAL HOT WEDGE FACTORY SEAM - SAMPLE 13

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	65.5	1.1	9	64.4	1.4	9
WATER 3	62.4	1.3	9	61.4	2.1	9
WATER 6	64.3	1.4	6	57.4	2.3	6
WATER 12	63.2	1.4	6	59.0	1.2	2-6
23° BRINE 3	55.5	2.4	9	60.4	1.2	2-9
23° BRINE 12	63.8	1.9	6	59.6	1.8	2
50° BRINE 3	69.0	1.8	6	62.6	1.8	6
50° BRINE 6	64.9	1.5	6	62.2	1.5	2
50° BRINE 12	66.6	1.7	2	64.7	1.1	2
PHENOL 3	61.2	1.9	6	64.2	2.4	6
PHENOL 6	61.9	1.1	6	60.5	1.3	6
PHENOL 12	64.7	2.1	2	57.3	5.1	2
HCL 3	61.6	1.5	6	61.7	1.1	6
HCL 6	63.0	4.0	7	59.6	1.3	2
HCL 12	60.2	2.8	2	59.7	2.5	2
NAOH 3	65.6	1.7	6	65.7	0.9	2
NAOH 6	60.0	4.0	6	61.1	3.9	2
NAOH 12	67.0	3.0	2	60.7	2.8	2
MEK 3	58.0	0.8	6	58.8	1.9	6
MEK 6	68.4	2.6	6	67.7	2.5	2
MEK 12	59.0	2.7	2	61.6	2.6	2
MCL 3	66.0	2.6	6	63.6	2.7	6
MCL 6	63.1	2.1	9	69.3	3.7	6
MCL 12	65.6	4.7	2	56.9	3.1	2
FURFURAL 3	58.0	2.2	6	61.7	3.5	6
FURFURAL 6	63.8	0.6	6	61.8	2.2	2
FURFURAL 12	58.2	3.9	2	62.4	3.8	2
H A 4	62.8	1.7	6	60.3	1.6	6
H A 8	62.2	0.6	6	63.6	2.8	6
H A 13	61.7	2.3	9	63.3	1.5	9-2
F/T 10	63.6	1.1	6	60.9	2.1	6
F/T 20	60.1	2.9	9	59.8	1.5	9
F/T 50	61.5	1.3	6	64.8	1.6	9
W/D 10	57.8	1.3	9	64.0	1.6	9
W/D 20	61.3	0.9	6	57.3	4.1	6
W/D 50	59.1	1.2	9	62.0	1.5	9
EMMAQUA				61.6	1.6	1-2

* 1.0 lbf/in = 175.1 N/m

TABLE 14. SEAM SHEAR AND PEEL STRENGTH - 30 MIL PVC (U) - SOLVENT ADHESIVE FACTORY SEAM - SAMPLE 14

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	57.2	1.0	2	14.8	0.9	4
WATER 3	54.1	2.0	2	15.4	0.5	4
WATER 6	56.5	1.7	2	16.1	0.7	3
WATER 12	56.9	2.4	2-6	16.3	0.6	3
23° BRINE 3	55.7	5.1	2-9	14.4	1.7	4
23° BRINE 12	55.1	3.2	1-2	16.0	0.3	3
50° BRINE 3	55.8	2.7	2-6	17.4	1.0	3
50° BRINE 6	54.6	3.8	1-2-6	17.8	1.3	3
50° BRINE 12	54.2	4.8	2	19.5	0.6	4
PHENOL 3	65.8	1.2	2-6	23.3	1.5	3
PHENOL 6	58.7	0.3	2	35.2	4.2	3
PHENOL 12	76.7	2.3	1-6	22.5	1.1	3
HCL 3	48.6	2.1	6	15.4	1.3	3
HCL 6	55.3	1.3	2	16.0	0.7	3
HCL 12	50.5	6.1	2	14.5	1.4	3
NAOH 3	78.4	1.9	2	25.4	1.3	3
NAOH 6	93.2	0.6	2-6	30.1	3.4	3
NAOH 12	117.6	5.8	2	10.6	3.9	3
MEK 3	52.4	1.9	2	15.4	0.7	3
MEK 6	56.4	1.2	1	15.9	0.2	3
MEK 12	56.3	--	1	31.0	1.5	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	51.8	2.4	1-2	4.5	7.0	3
FURFURAL 6	33.9	5.1	1	13.5	0.8	3
FURFURAL 12	56.8	4.4	1	26.2	1.7	3
H A 4	52.4	2.1	2	17.5	0.7	3
H A 8	51.9	0.4	2	17.6	0.4	3
H A 13	57.4	2.7	2	18.6	0.5	3
F/T 10	57.9	2.5	2	15.6	0.7	3
F/T 20	55.6	2.1	1-2-6	16.1	0.8	3
F/T 50	57.6	2.4	2-1	15.9	0.5	3
W/D 10	58.3	3.7	2-6	15.4	0.4	3
W/D 20	56.7	2.9	2-1	15.4	0.3	3
W/D 50	56.6	3.5	1-2	15.5	0.4	3
EMMAQUA				33.5	4.5	2

* 1.0 lbf/in = 175.1 N/m

TABLE 15. SEAM SHEAR AND PEEL STRENGTH - 30 MIL PVC (U) - THERMAL DIELECTRIC FACTORY SEAM - SAMPLE 15

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	52.9	2.9	2	38.1	1.2	2
WATER 3	52.5	0.5	2	39.5	0.5	2
WATER 6	52.0	1.4	2	37.9	2.0	2
WATER 12	53.2	0.9	2	41.9	1.6	2
23° BRINE 3	51.5	0.5	2	37.0	1.6	2
23° BRINE 12	47.9	0.7	2	37.2	1.4	2
50° BRINE 3	51.4	1.1	2	36.6	2.1	2
50° BRINE 6	51.8	0.7	2	38.8	0.4	2
50° BRINE 12	53.3	1.2	2	38.6	1.1	2
PHENOL 3	71.8	1.6	6	43.1	2.3	2-4
PHENOL 6	65.7	2.0	2	53.8	2.6	2
PHENOL 12	83.4	17.1	2	58.0	5.1	2
HCL 3	53.2	1.3	2-6	39.5	1.6	2
HCL 6	57.1	1.7	2	39.8	1.4	2
HCL 12	52.2	4.0	2	40.4	1.0	2
NAOH 3	123.5	3.8	6	23.9	6.5	2
NAOH 6	108.7	21.4	2-6	40.5	7.5	2
NAOH 12	121.2	5.5	2	17.9	9.9	2
MEK 3	50.1	2.1	2	35.4	1.0	2
MEK 6	56.4	2.1	2	37.9	1.8	2
MEK 12	50.6	6.0	2	30.6	1.8	2
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	53.8	3.6	2	37.1	1.6	2
FURFURAL 6	43.7	2.1	2	33.3	2.2	2
FURFURAL 12	66.5	3.0	6	46.6	2.9	2
H A 4	53.0	1.7	2	37.0	1.9	2
H A 8	52.4	1.5	2	39.4	0.8	2
H A 13	54.5	1.5	2	39.2	2.8	2
F/T 10	50.8	1.1	2	38.3	1.2	2
F/T 20	53.4	2.4	2	41.7	1.7	2
F/T 50	48.2	3.8	2-1	41.2	0.7	2
W/D 10	53.7	3.1	2	39.4	2.0	2
W/D 20	48.3	1.2	2	37.0	1.1	2
W/D 50	57.9	1.0	2	38.5	0.7	2
EMMAQUA				41.9	2.5	2

* 1.0 lbf/in = 175.1 N/m

TABLE 16. SEAM SHEAR AND PEEL STRENGTH - 30 MIL PVC/CPE (U) - THERMAL DIELECTRIC FACTORY SEAM - SAMPLE 16

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	38.2	3.8	2	29.8	0.9	2
WATER 3	27.5	3.0	2	20.1	1.7	2
WATER 6	23.2	0.6	2	16.2	2.3	2
WATER 12	22.7	1.6	2	12.9	2.9	2-4
23° BRINE 3	32.0	1.6	2	27.7	1.5	2
23° BRINE 12	22.0	2.0	2	21.2	0.6	2
50° BRINE 3	21.9	1.7	4-2	17.9	0.9	2
50° BRINE 6	23.3	2.0	2	16.8	0.4	2
50° BRINE 12	19.6	1.0	4	15.5	1.8	4-2
PHENOL 3	12.7	1.8	4	4.1	1.7	4
PHENOL 6	6.6	0.8	4	7.1	1.2	2
PHENOL 12	18.5	2.1	4	17.5	1.5	4-2
HCL 3	26.0	1.0	2-4	19.4	1.0	4
HCL 6	29.8	0.8	2	25.7	1.4	2
HCL 12	26.6	2.1	2	22.6	0.8	2
NAOH 3	33.3	1.4	2	2.8	2.4	2
NAOH 6	33.8	2.1	2	18.5	3.8	2
NAOH 12	34.6	3.5	2	17.9	1.5	2
MEK 3	18.8	0.9	2	15.6	0.9	2
MEK 6	19.1	1.3	4	16.1	1.1	2-6-4
MEK 12	22.0	2.3	2	15.9	1.0	2
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	15.9	4.8	2	11.2	1.5	4
FURFURAL 6	11.1	1.4	2-4	4.5	0.9	4
FURFURAL 12	--	--	--	--	--	--
H A 4	27.6	1.8	2	15.0	1.3	2
H A 8	21.6	1.9	2	14.8	0.7	2
H A 13	17.3	1.4	2	15.1	1.6	2
F/T 10	24.8	2.5	2-4	23.1	2.0	4
F/T 20	32.5	1.6	2-4	21.6	1.5	4
F/T 50	28.2	2.5	2-4	20.1	3.9	4
W/D 10	26.1	3.3	2	19.0	1.9	4-6
W/D 20	31.1	2.4	2	21.5	0.7	2
W/D 50	31.4	5.4	2	27.1	1.2	2
EMMAQUA				19.5	0.7	2-4

* 1.0 lbf/in = 175.1 N/m

TABLE 17. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CPE (S) - BODIED SOLVENT ADHESIVE FIELD SEAM - SAMPLE 17

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	94.3	1.9	7	71.8	2.9	6
WATER 3	37.3	1.2	5	55.2	2.7	6-7
WATER 6	39.4	2.7	7	58.2	7.2	7
WATER 12	39.9	3.8	7	52.7	5.5	7
23° BRINE 3	45.7	1.5	5	68.9	9.3	7
23° BRINE 12	47.8	2.8	7	54.0	8.1	7
50° BRINE 3	57.8	3.5	7	67.4	9.8	7
50° BRINE 6	52.3	2.3	7	73.1	3.1	7
50° BRINE 12	89.6	9.6	7	67.5	2.1	7
PHENOL 3	12.3	0.4	5	21.5	3.7	5
PHENOL 6	6.5	0.7	5	17.0	2.2	5
PHENOL 12	9.2	0.4	5	12.8	1.8	5
HCL 3	58.9	2.5	7	65.7	4.2	7
HCL 6	50.1	3.2	7	66.5	6.8	7-2
HCL 12	52.9	1.2	5	46.9	3.1	5
NAOH 3	27.3	3.2	5	45.7	5.5	7
NAOH 6	22.9	7.5	7	8.6	0.8	5
NAOH 12	7.8	0.6	7	20.8	6.3	7
MEK 3	36.7	2.1	7	56.1	8.4	7
MEK 6	35.4	1.9	5	52.9	2.1	7
MEK 12	34.3	6.2	5	51.0	3.9	5
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	63.0	5.4	7	66.8	2.9	7
FURFURAL 6	42.4	2.4	5	39.0	3.4	5
FURFURAL 12	55.4	1.7	5	56.5	4.5	5
H A 4	92.9	3.1	7	74.9	3.6	7
H A 8	96.4	4.7	7	69.1	5.3	7
H A 13	98.0	4.2	1-7-6	72.7	3.5	3-7
F/T 10	43.6	1.5	7	65.2	5.1	7
F/T 20	40.0	2.3	7	64.1	4.8	7
F/T 50	38.9	2.1	7	67.4	7.4	7
W/D 10	53.3	2.4	7	35.1	4.0	7
W/D 20	55.0	1.1	7	66.5	6.1	7
W/D 50	71.9	4.8	7	70.6	3.5	7
EMMAQUA				61.2	10.8	7-8

* 1.0 lbf/in = 175.1 N/m

TABLE 18. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CPE (S) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 18

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	124.5	1.1	7	23.4	5.1	3
WATER 3	113.8	10.6	7	18.7	4.5	3
WATER 6	105.6	4.4	7	17.6	3.3	3
WATER 12	111.1	3.8	7	19.6	1.1	3
23° BRINE 3	117.7	6.2	7	15.6	1.8	3
23° BRINE 12	113.4	7.4	7	21.4	3.4	3
50° BRINE 3	115.4	9.5	6	16.9	2.2	3
50° BRINE 6	116.6	2.1	7	14.5	2.0	3
50° BRINE 12	108.4	17.6	3-7	3.0	0.9	3
PHENOL 3	48.8	1.0	5	3.4	0.3	3
PHENOL 6	36.9	2.7	7	2.1	0.5	3
PHENOL 12	56.4	3.2	5	3.2	1.4	3
HCL 3	111.5	2.3	7	19.5	4.1	4
HCL 6	129.3	8.5	7	11.4	2.7	3
HCL 12	112.9	30.3	7	12.1	6.1	3
NAOH 3	60.0	15.9	4	0.0	0.0	NA
NAOH 6	24.0	19.1	3	0.0	0.0	3
NAOH 12	--	--	--	--	--	--
MEK 3	115.9	4.0	7	17.3	3.2	4
MEK 6	126.0	9.9	7	15.4	1.9	3
MEK 12	108.2	3.5	5	12.6	0.7	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	99.0	15.0	6	17.4/24.5	6.8/4.4	8-3
FURFURAL 6	86.2	4.6	5	9.8	4.5	3
FURFURAL 12	128.5	8.6	5-6	26.7/10.6	3.0/0.8	3-8
H A 4	123.0	6.5	7	14.8	1.1	3-4
H A 8	130.1	1.9	7-1	16.1	2.4	3
H A 13	122.9	5.7	1	15.1	2.5	3
F/T 10	108.8	4.3	7	18.3	3.1	3
F/T 20	115.1	8.1	7	14.6	1.0	3
F/T 50	102.6	4.5	7	19.4	1.7	3
W/D 10	116.5	4.4	7	17.4	1.4	3
W/D 20	114.4	3.6	7	16.2	1.6	3
W/D 50	117.2	5.3	7-6-1	18.0	3.2	3
EMMAQUA				17.7	0.3	3

* 1.0 lbf/in = 175.1 N/m

TABLE 19. SEAM SHEAR AND PEEL STRENGTH - 30 MIL CSPE (S) - BODIED SOLVENT ADHESIVE - SAMPLE 19

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	31.2	0.8	7	31.7/22.5	1.6/1.3	8
WATER 3	31.8	0.5	7	26.8	2.1	3-4
WATER 6	31.1	0.9	7	29.7	1.6	3
WATER 12	35.5	1.2	7	27.9	3.3	7
23° BRINE 3	31.3	1.1	7	32.2	3.1	7
23° BRINE 12	32.5	1.1	7	30.2	1.5	7
50° BRINE 3	34.0	1.5	7	27.9/17.3	3.6/0.0	3-8
50° BRINE 6	34.9	0.9	7	29.5/14.6	2.1/1.1	8-6
50° BRINE 12	39.5	0.7	7	23.7/17.0	3.4/0.6	8-7
PHENOL 3	25.2	1.0	5	23.1	3.1	5
PHENOL 6	21.3	0.8	7	18.9	1.9	4-7
PHENOL 12	29.8	0.7	7	25.2	1.5	7
HCL 3	32.5	1.9	7	30.5	2.3	7
HCL 6	31.2	0.8	7	15.1	5.6	3
HCL 12	30.0	1.0	7	29.5	1.6	7
NAOH 3	24.6	1.3	5	26.1	2.0	7-3
NAOH 6	17.6	1.7	7	16.4	3.0	3
NAOH 12	18.8	1.7	7	24.9	2.8	7
MEK 3	32.8	1.6	7	30.9	2.3	7
MEK 6	33.4	1.5	7	30.1	2.8	7
MEK 12	31.5	2.1	7	32.2	2.2	7
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	34.7	1.3	7	14.7	5.5	3
FURFURAL 6	32.7	0.5	7	27.4	2.7	7-8
FURFURAL 12	35.4	0.5	7	15.6	1.3	7
H A 4	33.4	0.9	7	22.9/14.7	4.3/1.1	8
H A 8	36.6	1.5	7	19.5/17.9	3.6/4.2	3-8
H A 13	39.9	1.0	7	21.4/13.3	2.2/0.9	3-8
F/T 10	32.1	1.1	7	29.4	2.7	3-5-6
F/T 20	30.6	1.2	7	28.4	0.9	7
F/T 50	33.5	1.0	7	29.0	1.6	7
W/D 10	33.0	0.5	7	32.2	2.0	7
W/D 20	32.0	0.9	7	28.8	1.9	7
W/D 50	32.9	1.8	7	30.8	4.0	7
EMMAQUA						

* 1.0 lbf/in = 175.1 N/m

TABLE 20. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - BODIED SOLVENT ADHESIVE FIELD SEAM - SAMPLE 20

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	65.0	2.9	7	31.0	7.3	3
WATER 3	44.1	2.6	7	20.5	2.9	3-4
WATER 6	44.8	1.7	7	17.9	1.5	3
WATER 12	45.1	1.2	7	22.0	2.1	3
23° BRINE 3	41.2	3.5	7	21.2	4.3	3-4
23° BRINE 12	47.0	2.5	7	30.5	2.5	3
50° BRINE 3	52.8	2.5	7	11.5	1.9	3
50° BRINE 6	53.0	3.1	7	10.9	2.3	3
50° BRINE 12	90.0	3.0	7	7.1	0.4	3
PHENOL 3	25.6	1.7	4	2.9	0.8	4
PHENOL 6	17.5	1.9	4	10.5	2.5	4
PHENOL 12	27.5	1.4	5	15.0	2.5	3
HCL 3	53.5	3.7	7	12.2	9.7	3
HCL 6	40.5	14.6	7	31.9	7.6	3
HCL 12	57.5	2.6	5	24.5	2.4	3
NAOH 3	41.2	1.7	7	11.6	0.8	3
NAOH 6	24.2	2.9	5-7	20.2	2.7	3
NAOH 12	19.0	0.8	7	19.1	1.5	3
MEK 3	46.5	1.5	7	3.8	0.6	3
MEK 6	43.9	0.8	5	17.6	2.4	3
MEK 12	45.2	2.6	5	12.2	8.4	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	38.8	3.3	5	7.4	1.5	3
FURFURAL 6	40.0	0.8	5	10.9	2.9	3
FURFURAL 12	34.9	0.6	5	15.0	4.3	3
H A 4	102.1	3.3	7	6.8	1.1	3
H A 8	101.3	3.3	7	3.5	0.2	3
H A 13	106.6	2.2	7	4.8	0.6	3
F/T 10	49.8	3.3	7	16.5	3.8	3
F/T 20	39.0	2.0	7	14.9	4.5	3
F/T 50	39.9	1.7	7	16.4	2.0	3
W/D 10	37.8	5.7	7	16.2	3.0	3
W/D 20	39.4	3.6	7	21.6	1.3	3
W/D 50	45.7	2.6	5	17.4	0.9	3
EMMAQUA						

* 1.0 lbf/in = 175.1 N/m

TABLE 21. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - ADHESIVE FIELD SEAM - SAMPLE 21

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	65.0	5.6	7	32.8/17.7	5.0/1.8	8
WATER 3	58.4	2.8	7	31.7/20.3	3.5/0.9	8
WATER 6	69.6	3.8	7	40.0/18.3	4.4/1.4	8
WATER 12	69.7	3.8	7	32.6/16.1	5.0/1.4	8
23° BRINE 3	47.9	1.5	7	32.4/17.3	4.9/1.9	8
23° BRINE 12	65.6	1.5	7	29.5/16.4	2.9/1.9	8
50° BRINE 3	94.3	31.7	7	32.0/14.6	4.4/2.3	8
50° BRINE 6	59.7	5.3	7	34.2/14.4	1.4/0.7	8
50° BRINE 12	70.1	1.7	7	37.5/15.2	1.8/0.6	8
PHENOL 3	54.7	0.6	5	38.2/21.8	4.4/2.5	8
PHENOL 6	28.4	17.8	7	28.2/12.0	3.5/0.4	8
PHENOL 12	43.3	1.5	5	36.6/17.1	4.5/3.7	8
HCL 3	89.5	7.4	7	35.1	2.5	4
HCL 6	93.5	7.0	7	26.8/14.6	2.4/1.3	8
HCL 12	121.5	20.4	5	35.3/16.2	4.6/1.4	8
NAOH 3	54.3	11.9	7	27.7/17.5	1.8/1.2	8
NAOH 6	37.5	14.9	5-7	30.0/18.9	4.8/1.3	8
NAOH 12	11.6	3.1	7	26.4/15.3	4.3/1.1	8
MEK 3	103.0	19.6	7	24.9	4.4	4
MEK 6	79.7	17.5	7-5	32.9/15.3	2.9/1.1	8
MEK 12	69.1	7.8	5	34.4/16.4	2.4/0.6	8
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	64.5	11.7	6	27.2/15.5	3.7/1.6	8
FURFURAL 6	75.7	3.4	5	31.2/15.2	9.1/1.3	8
FURFURAL 12	58.0	11.5	5	34.7/13.5	3.2/0.4	8
H A 4	173.2	9.6	7	30.9/13.4	3.6/0.2	8
H A 8	151.3	14.5	7	27.4/12.4	1.5/0.5	3-8
H A 13	178.2	6.4	7-2	29.5/12.0	0.8/0.3	8
F/T 10	62.3	14.9	7	36.0/15.7	0.8/0.6	8
F/T 20	50.7	3.3	7	27.5/16.0	3.0/0.8	8
F/T 50	71.4	8.6	7	35.4/17.3	1.9/1.8	8
W/D 10	58.8	6.8	7	34.3/18.1	6.3/1.1	8
W/D 20	75.2	6.3	7	30.7/18.0	4.4/3.9	8
W/D 50	63.5	5.2	7	34.0/15.8	3.4/1.2	8
EMMAQUA				24.5/13.7	3.6/0.9	8

* 1.0 lbf/in = 175.1 N/m

TABLE 22. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - BODIED SOLVENT ADHESIVE FIELD SEAM - SAMPLE 22

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	90.0	4.5	7	53.4	3.1	6
WATER 3	72.5	4.5	5	57.1	7.1	7
WATER 6	76.9	1.6	7	64.8	4.2	7
WATER 12	84.9	3.4	7	68.7	5.3	7
23° BRINE 3	80.2	3.5	5	69.3	2.5	7
23° BRINE 12	79.2	3.4	7	74.0	6.0	7
50° BRINE 3	94.0	5.9	7	64.3	3.9	7
50° BRINE 6	92.6	3.0	7	63.0	4.8	7
50° BRINE 12	96.6	3.1	7	58.5	4.5	7
PHENOL 3	18.8	5.9	5	30.4	4.5	4
PHENOL 6	16.0	0.9	5-7	31.4	2.7	5
PHENOL 12	22.8	1.0	5	20.0	5.3	5
HCL 3	64.7	5.3	7	63.6	5.9	7
HCL 6	63.6	3.9	7	68.0	4.9	7-2
HCL 12	74.5	4.2	5	58.0	10.2	5
NAOH 3	44.8	1.3	7	54.2	6.9	7
NAOH 6	35.3	2.8	7	25.1	7.7	3-7
NAOH 12	19.9	7.7	7	52.8	7.1	7
MEK 3	38.1	0.7	7	67.8	6.6	6
MEK 6	74.3	5.6	5-7	72.9	6.0	7-5
MEK 12	74.8	4.0	7	60.1	2.2	5
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	73.0	5.7	7-5	74.3	4.8	7
FURFURAL 6	49.4	1.7	5	65.1	11.8	5
FURFURAL 12	30.5	6.3	5	37.5	1.6	5
H A 4	89.6	6.5	1-7	58.0	7.2	5-7
H A 8	92.6	3.7	7	34.3	9.3	3-5
H A 13	97.4	5.4	2-6	51.5	3.5	6-5-7
F/T 10	79.5	3.7	7	62.9	2.9	7
F/T 20	78.3	3.6	7	67.2	5.3	7
F/T 50	74.6	9.4	7	69.4	3.3	7
W/D 10	78.0	6.1	7	67.0	7.1	7
W/D 20	90.3	3.2	7	62.4	3.9	7
W/D 50	87.6	2.9	7	65.1	3.2	7-6
EMMAQUA				22.1	6.1	3

* 1.0 lbf/in = 175.1 N/m

TABLE 23. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 23

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	118.7	1.7	7	30.0/14.8	5.8/0.3	8
WATER 3	74.7	7.0	7	32.3/16.3	0.6/0.7	8
WATER 6	72.0	2.0	7	30.1/16.9	2.8/0.8	8
WATER 12	99.5	5.6	7	33.1/16.0	1.0/0.4	8
23° BRINE 3	80.4	5.8	7	31.1/16.7	4.4/0.4	8
23° BRINE 12	98.7	3.9	7	36.0/16.1	1.1/0.4	8
50° BRINE 3	117.2	11.9	7	24.6/13.3	1.6/0.5	8
50° BRINE 6	115.1	5.1	7	29.8/14.5	3.4/0.6	8
50° BRINE 12	141.3	9.6	7	30.3/12.5	0.7/0.2	8
PHENOL 3	29.8	4.0	5	33.0/20.2	2.5/0.7	8
PHENOL 6	38.5	3.5	7	32.6/19.8	3.3/8.2	8
PHENOL 12	55.9	6.8	5	30.0/21.9	2.5/4.1	8
HCL 3	86.3	7.9	7	32.3/19.3	6.4/1.7	8
HCL 6	92.4	4.2	7	34.7/19.0	5.9/0.3	8
HCL 12	92.4	5.2	5	29.5/21.7	1.7/3.4	8
NAOH 3	98.0	9.5	5-7	25.5/18.4	1.0/1.4	8
NAOH 6	66.1	15.1	7	29.2/15.7	5.4/1.6	8
NAOH 12	22.6	0.7	7	23.3/13.7	0.6/0.6	7-8
MEK 3	80.5	3.5	7	28.6/16.3	5.3/0.6	8
MEK 6	98.1	4.8	5	33.4/16.6	1.3/1.0	8
MEK 12	104.7	8.5	7	31.0/17.4	2.3/0.8	8
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	97.0	8.7	7	30.6/18.6	5.5/1.7	8
FURFURAL 6	38.7	3.1	5	26.2/15.4	2.1/0.6	8
FURFURAL 12	84.0	4.8	5	31.2/16.6	2.5/0.4	8
H A 4	154.4	14.2	7	24.7/13.3	1.6/0.3	8
H A 8	158.9	8.8	7	24.4/12.3	2.7/0.2	8
H A 13	164.0	16.1	7-6-2	23.2/11.6	1.6/0.2	8
F/T 10	84.9	7.8	7	28.8/16.4	2.8/1.0	8
F/T 20	76.4	7.3	7	36.3/17.7	7.9/2.2	8
F/T 50	72.4	4.3	7	35.7/17.6	5.1/2.3	8
W/D 10	73.2	5.4	7	34.1/16.5	2.8/0.7	8
W/D 20	85.8	3.7	7	30.8/17.6	3.7/1.6	8
W/D 50	92.0	9.9	7	33.4/16.5	2.8/1.5	8
EMMAQUA				22.4/13.5	6.7/1.4	8-3

* 1.0 lbf/in = 175.1 N/m

TABLE 24. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 24

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	138.4	7.1	7	31.7/15.1	3.1/2.3	8
WATER 3	101.6	3.2	7	30.7/12.7	1.7/0.8	8
WATER 6	105.5	1.9	7	29.5/13.2	2.2/0.5	8
WATER 12	124.1	2.2	7	28.8/12.4	1.5/0.6	4-8
23° BRINE 3	85.8	3.2	7	29.4/13.8	0.9/0.5	8
23° BRINE 12	106.8	3.0	7	29.8/9.6	2.8/0.6	8
50° BRINE 3	134.8	3.1	7	25.5/11.9	2.3/0.3	8
50° BRINE 6	117.1	8.4	7	30.7/12.5	3.3/0.2	8
50° BRINE 12	120.1	5.1	7	23.2/12.5	4.0/0.7	8-3
PHENOL 3	64.0	1.6	5	21.8/12.8	10.0/1.3	8
PHENOL 6	49.9	1.5	7	23.1/18.3	5.3/2.0	8
PHENOL 12	76.4	3.4	5	22.9/14.8	3.7/3.2	8
HCL 3	105.8	1.1	7	30.2/15.4	2.2/0.5	8
HCL 6	114.0	4.7	7	28.3/14.4	2.7/1.1	8
HCL 12	138.7	5.6	7	28.2/16.0	3.3/0.4	8
NAOH 3	99.9	5.3	7	26.8/16.4	9.9/2.5	8
NAOH 6	72.7	2.6	5	19.5	4.8	3
NAOH 12	34.9	9.3	7	28.6/14.6	4.5/0.8	8
MEK 3	145.5	4.8	7	22.3/14.0	5.8/0.0	4-8
MEK 6	131.6	7.7	7	21.7	2.3	3-8
MEK 12	119.5	12.0	5	28.8/14.1	1.5/1.3	8
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	148.0	3.5	7	18.0	1.5	3
FURFURAL 6	122.9	4.0	7	17.8	2.6	3
FURFURAL 12	148.7	5.2	5	24.5/13.8	6.8/1.1	8-3
H A 4	159.2	7.7	1-2-7	26.5/11.1	1.9/0.4	8
H A 8	160.4	5.2	2-7	23.1	2.9	3
H A 13	166.1	8.2	2-6	22.1/9.8	2.3/0.1	8-3
F/T 10	83.4	9.0	7	31.1/12.7	1.2/0.3	8
F/T 20	103.6	2.2	7	28.6/12.0	1.7/0.8	8
F/T 50	91.9	3.9	7	29.3/12.5	4.4/0.3	8
W/D 10	99.0	3.3	7	29.6/12.7	3.8/0.6	8
W/D 20	117.9	8.7	7	30.9/12.7	2.4/0.4	8
W/D 50	130.3	13.1	7	28.2/13.2	4.9/0.6	8-3
EMMAQUA				11.7	1.0	3

* 1.0 lbf/in = 175.1 N/m

TABLE 25. SEAM SHEAR AND PEEL STRENGTH - 36 MIL CSPE (S) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 25

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	97.4	5.0	7	29.5/16.2	2.4/3.6	8
WATER 3	81.6	1.8	7	33.1/18.3	0.8/0.9	8
WATER 6	76.5	2.0	7	37.2/16.6	1.3/1.7	8
WATER 12	85.0	5.8	7	32.3/13.5	4.9/0.6	8
23° BRINE 3	68.0	2.9	7	33.1/15.8	4.9/1.0	8
23° BRINE 12	84.1	5.5	7	26.9/13.4	2.7/0.2	8
50° BRINE 3	135.8	6.2	6	24.7/11.6	4.0/0.7	3-8
50° BRINE 6	119.8	2.4	7	28.1/12.3	2.1/0.6	8
50° BRINE 12	156.9	7.3	7	25.4/12.9	2.0/0.4	8
PHENOL 3	38.8	3.1	5	29.6/14.9	2.7/2.2	8-4
PHENOL 6	24.6	5.6	7	30.4/22.3	2.0/1.0	8
PHENOL 12	55.9	15.2	5	31.4	1.9	5
HCL 3	124.9	11.4	7	37.3/21.8	7.0/0.2	8
HCL 6	81.3	5.5	5-7	34.0/17.8	4.1/2.5	8
HCL 12	70.0	1.3	5	33.1/21.6	2.4/3.8	8
NAOH 3	80.0	5.7	5-7	25.1/16.4	9.8/4.1	8
NAOH 6	61.1	2.3	5	32.4/14.0	2.3/0.6	8
NAOH 12	32.2	12.6	7	24.3/24.9	2.0/0.9	8-3
MEK 3	122.5	8.7	7	30.8/18.4	7.8/2.4	8
MEK 6	71.8	5.6	5	30.1/13.1	2.6/0.5	8
MEK 12	83.2	7.6	5	21.7/10.2	4.2/4.9	3-8
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	144.8	7.4	7	20.8	10.1	3-8
FURFURAL 6	63.9	4.1	5	26.1/12.4	3.7/1.4	8
FURFURAL 12	82.5	6.0	5	30.1/16.1	0.8/5.7	8
H A 4	118.0	4.6	7	29.3/13.3	2.1/0.5	8
H A 8	104.0	6.8	7-1	27.0/12.8	7.4/0.5	3-8
H A 13	151.1	7.3	7-2	27.6/11.9	1.1/0.3	8-3
F/T 10	62.4	3.8	7	29.2	2.4	5
F/T 20	75.0	1.9	7	29.6/16.5	3.2/2.0	8-5
F/T 50	58.9	1.3	7	39.2	9.1	5-8
W/D 10	80.7	2.1	7	33.1/17.4	4.8/2.8	8
W/D 20	73.3	3.9	7	32.9/21.7	3.3/4.0	8
W/D 50	97.2	4.2	7	33.4/13.5	1.6/1.0	8
EMMAQUA				25.0/12.5	4.0/0.2	8

* 1.0 lbf/in = 175.1 N/m

TABLE 26. SEAM SHEAR AND PEEL STRENGTH - 38 MIL EIA (S) - THERMAL HOT AIR FIELD SEAM - SAMPLE 26

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	356.6	4.5	6	39.3/16.0	1.2/0.3	8
WATER 3	373.8	6.2	2-6	38.7/13.9	2.4/0.7	8
WATER 6	360.0	28.1	1	36.7/13.3	2.1/0.3	8
WATER 12	376.4	19.8	1-6	41.9/13.6	2.9/0.6	8
23° BRINE 3	391.0	6.4	2-6	41.0/14.6	4.6/0.5	8
23° BRINE 12	384.5	5.1	1-2-6	44.7/14.1	6.0/0.2	8
50° BRINE 3	363.8	21.2	1-6	39.1/14.9	6.1/0.4	8
50° BRINE 6	354.0	29.6	1-2-6	38.2/15.3	5.3/0.7	8
50° BRINE 12	339.3	75.9	1-2-6	43.8/18.3	2.8/0.4	8
PHENOL 3	150.0+	NA	9	19.3	2.8	4
PHENOL 6	150.0+	NA	9	17.3/6.8	2.1/0.7	8
PHENOL 12	356.2	35.6	2	24.2/8.3	2.8/0.8	8
HCL 3	150.0+	NA	9	31.3/17.1	8.0/0.6	8
HCL 6	150.0+	NA	9	29.4/16.4	5.3/1.9	8
HCL 12	337.5	23.0	7	29.1/18.8	4.8/1.2	8
NAOH 3	150.0+	NA	9	31.7/17.9	8.1/0.5	8
NAOH 6	150.0+	NA	9	39.9/15.6	5.9/1.5	8
NAOH 12	165.3	64.9	2	38.0/15.9	2.7/1.1	8
MEK 3	150.0+	NA	9	34.2/17.9	7.4/1.2	8
MEK 6	150.0+	NA	9	38.1/18.0	7.9/1.1	8
MEK 12	54.1	48.3	3-6	1.0	0.3	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	150.0+	NA	9	31.4/18.9	9.2/1.4	8
FURFURAL 6	150.0+	NA	9	29.3/19.4	5.2/1.3	8
FURFURAL 12						
H A 4	367.1	26.6	1-2-6	47.0/17.0	5.0/0.8	8
H A 8	369.5	15.5	1-6	37.2/20.9	4.2/0.3	8
H A 13	368.1	13.9	2-6	38.0/21.9	1.8/1.6	8
F/T 10	378.1	16.0	1-2-6	35.8/13.1	0.8/0.6	8
F/T 20	362.8	25.8	2-6	37.5/13.7	4.0/0.7	8
F/T 50	346.0	24.3	6-1	33.7/13.0	4.0/0.3	8
W/D 10	360.3	28.4	1-6	43.0/15.4	5.0/1.1	8
W/D 20	382.2	13.2	2-6	34.2/17.8	2.2/2.2	8
W/D 50	379.6	25.2	1-6-2	45.0/16.8	2.5/1.0	8
EMMAQUA				24.4/15.9	7.8/0.6	8

* 1.0 lbf/in = 175.1 N/m

TABLE 27. SEAM SHEAR AND PEEL STRENGTH - 30MIL EPDM (S) - GUMTAPE/CEMENT FIELD SEAM - SAMPLE 27

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	91.4	1.5	7	8.6	1.8	3
WATER 3	86.7	2.6	7	8.7	0.8	3
WATER 6	87.2	0.6	6	6.9	0.9	3
WATER 12	89.6	1.3	7	5.5	0.3	3
23° BRINE 3	89.2	4.5	7	7.8	0.5	3
23° BRINE 12	82.7	1.9	7	6.6	0.7	3
50° BRINE 3	87.3	2.2	7	7.5	0.3	3
50° BRINE 6	84.6	1.4	7	7.8	0.7	3
50° BRINE 12	88.2	5.2	7	16.5	1.9	3
PHENOL 3	61.3	6.3	5	5.9	1.7	4
PHENOL 6	42.9	22.8	7	6.1	0.5	3
PHENOL 12	70.8	9.1	5	5.2	0.1	3
HCL 3	58.9	0.8	7	5.4	0.6	4
HCL 6	65.6	14.0	5	5.0	1.0	3
HCL 12	46.6	5.2	7	6.8	0.4	3
NAOH 3	44.2	7.9	5-7	6.4	1.5	4-3
NAOH 6	22.0	7.0	5	5.1	1.8	3-4
NAOH 12	9.6	9.1	7	6.5	0.7	3
MEK 3	70.9	8.4	7	5.5	0.4	3
MEK 6	50.5	5.9	5	8.3	0.8	3
MEK 12	70.8	5.9	7	13.9	1.2	3
MCL 3	—	—	—	—	—	—
MCL 6	55.5	6.7	7-5	29.0	5.6	6
MCL 12	100.4	13.3	5	14.0	2.0	3
FURFURAL 3	69.0	5.4	7	6.9	1.5	3
FURFURAL 6	55.4	1.9	5	5.2	1.1	3
FURFURAL 12	65.3	1.6	5	6.9	0.6	3
H A 4	95.3	1.4	7	11.4	1.9	3
H A 8	95.0	1.4	7	10.7	1.2	3
H A 13	104.3	2.3	5-7	17.7	5.1	3
F/T 10	86.2	2.5	7	5.8	0.4	3
F/T 20	82.7	6.6	7	6.1	0.7	3
F/T 50	86.2	6.1	7	6.3	0.8	3
W/D 10	94.2	3.6	7	5.4	0.6	3
W/D 20	84.9	1.8	7-3	5.7	0.3	3
W/D 50	89.9	2.7	5-3-7	6.8	1.0	3
EMMAQUA				11.0	2.1	3

* 1.0 lbf/in = 175.1 N/m

TABLE 28. SEAM SHEAR AND PEEL STRENGTH - 30 MIL CPE (U) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 28

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	33.8	0.9	2	17.0	0.7	3
WATER 3	32.7	1.3	2	15.4	0.6	3
WATER 6	31.8	1.4	2	12.4	0.8	3
WATER 12	33.6	2.8	1-2	6.0	0.3	3
23° BRINE 3	36.3	0.5	2	17.5	0.9	3-6
23° BRINE 12	26.3	1.6	2	16.0	1.3	2-3-6
50° BRINE 3	32.8	3.5	2	16.6	1.4	6
50° BRINE 6	30.4	1.5	2	16.5	0.5	1-3-6
50° BRINE 12	34.0	1.9	2	15.4	1.3	6-3
PHENOL 3	9.5	2.0	2	0.5	0.2	3
PHENOL 6	6.0	1.5	2-6	3.7	0.9	3
PHENOL 12	16.8	2.4	2	5.9	1.1	3
HCL 3	31.6	4.1	2	13.2	3.5	3
HCL 6	23.3	11.5	2	14.9	1.3	3-6
HCL 12	34.6	1.2	2	17.0	1.3	3-2
NAOH 3	39.0	3.3	2	15.1	1.5	3-4
NAOH 6	32.3	3.5	2	12.1	0.9	3
NAOH 12	38.8	6.3	2	10.5	2.0	3
MEK 3	26.1	1.3	2-6	14.4	1.8	3
MEK 6	26.7	1.5	2	14.8	1.4	6-3
MEK 12	17.6	0.8	1	13.8	0.4	3
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	14.1	0.0	2	4.9	0.8	3
FURFURAL 6	14.4	0.3	2	4.5	0.6	3
FURFURAL 12	17.4	0.2	3	4.2	1.1	3
H A 4	26.3	0.1	2	16.7	0.8	3-4-6
H A 8	29.4	0.5	2	17.8	0.4	3
H A 13	32.1	1.5	2	15.6	1.5	3-6
F/T 10	33.2	1.8	2	9.6	1.9	3
F/T 20	37.0	2.1	2-6-1	10.4	0.9	3
F/T 50	35.1	2.3	2-1	14.3	0.4	3
W/D 10	32.8	2.7	2-1	7.6	0.7	3
W/D 20	31.8	2.6	9-2-1	7.7	0.6	3
W/D 50	33.8	2.1	2-1	9.7	1.7	3
EMMAQUA				16.3	1.4	4

* 1.0 lbf/in = 175.1 N/m

TABLE 29. SEAM SHEAR AND PEEL STRENGTH - 30 MIL CPE (U) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 29

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	33.6	1.1	2	12.3	1.2	3
WATER 3	35.5	1.8	9	15.3	1.7	3
WATER 6	37.6	2.3	2	9.9	1.9	3
WATER 12	35.1	1.3	9	5.4	0.2	3
23° BRINE 3	32.9	0.8	2	15.5	0.9	3
23° BRINE 12	30.4	0.2	2	16.5	1.1	3
50° BRINE 3	34.3	3.3	2	16.6	1.4	6
50° BRINE 6	34.8	1.0	2	15.3	1.5	3
50° BRINE 12	36.0	1.4	2	13.5	0.7	3
PHENOL 3	4.3	0.5	3	0.3	NA	3
PHENOL 6	8.2	1.1	6	2.9	1.6	3
PHENOL 12	15.8	2.0	9	4.4	1.0	3
HCL 3	38.4	0.9	2	14.2	1.6	3
HCL 6	35.2	2.5	2	13.3	1.5	3
HCL 12	34.2	2.7	2	11.4	0.5	3
NAOH 3	39.3	3.1	2	12.7	1.5	3-4
NAOH 6	35.7	1.7	2	17.4	0.5	3
NAOH 12	40.0	6.1	2	13.6	2.1	3
MEK 3	31.8	0.6	2	11.7	2.0	4
MEK 6	30.5	1.3	2	14.5	1.1	3
MEK 12	16.9	8.8	2	9.2	1.1	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	18.3	1.3	2	4.1	2.0	3
FURFURAL 6	19.2	0.9	9	2.5	0.3	3
FURFURAL 12	18.2	0.9	3	4.6	2.5	3
H A 4	34.4	1.1	2-6	15.8	0.7	3
H A 8	30.3	1.0	2	16.5	1.5	3
H A 13	32.8	1.1	2	14.2	1.3	3
F/T 10	33.5	0.3	2-9	7.8	1.4	3
F/T 20	35.7	3.7	2	8.5	0.8	3
F/T 50	35.5	1.4	9-6-5	7.0	0.2	3
W/D 10	35.9	3.2	2-6	7.6	1.0	3
W/D 20	33.5	0.5	9-2	6.0	0.5	3
W/D 50	37.5	1.1	2	14.1	1.4	3
EMMAQUA				13.0	1.5	3

* 1.0 lbf/in = 175.1 N/m

TABLE 30. SEAM SHEAR AND PEEL STRENGTH - 30 MIL HDPE (U) - EXTRUSION FILLET WELD FIELD SEAM - SAMPLE 30

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	73.7	4.0	9	72.3	1.0	2
WATER 3	84.6	1.2	9	85.5	2.5	2
WATER 6	83.0	2.1	6	76.7	8.4	2-6
WATER 12	84.6	3.6	6	80.2	6.4	2
23° BRINE 3	83.8	0.8	9	82.2	1.8	2
23° BRINE 12	81.4	4.5	6	78.1	7.1	2
50° BRINE 3	82.4	7.0	6	78.5	6.3	2-6
50° BRINE 6	79.8	1.3	6	75.3	6.3	2-6
50° BRINE 12	89.7	3.4	2-1	88.0	3.4	2
PHENOL 3	91.0	5.7	6	87.0	2.8	6
PHENOL 6	91.0	2.3	6	76.3	13.9	8
PHENOL 12	69.5	2.1	6-2	72.3	3.3	2
HCL 3	88.6	1.5	6	80.6	5.0	2
HCL 6	65.2	6.0	6	68.4	2.2	2
HCL 12	78.1	3.5	6	72.7	4.5	6-2
NAOH 3	78.4	5.7	6	69.0	6.5	2-6
NAOH 6	71.3	3.7	6	72.6	14.6	2
NAOH 12	73.6	3.7	2	73.5	3.2	2-6
MEK 3	77.5	3.5	6	65.4	7.5	6
MEK 6	83.6	3.3	6	74.5	6.6	2
MEK 12	72.4	3.6	1	65.7	11.0	1-2
MCL 3	85.0	3.1	6	75.9	7.8	2-6
MCL 6	70.2	4.0	9	76.4	4.6	6-2
MCL 12	79.0	4.2	2	76.1	2.2	2
FURFURAL 3	83.7	1.9	6	86.3	2.9	2
FURFURAL 6	62.8	21.5	6	66.2	26.8	6-2
FURFURAL 12	69.9	2.3	2	76.3	3.9	6
H A 4	79.2	3.0	6	76.1	5.4	2-6
H A 8	85.2	2.3	6	76.6	5.0	2
H A 13	84.6	1.8	9	79.5	2.3	2
F/T 10	82.3	2.1	6	83.9	2.0	2-6
F/T 20	72.0	15.1	2-9	58.3	24.1	2-9
F/T 50	81.3	3.8	6	82.4	2.2	2
W/D 10	89.6	2.8	9	76.7	13.3	2-9
W/D 20	79.4	5.2	6	80.4	1.6	6
W/D 50	79.7	0.4	2-9	78.9	5.6	2-9
EMMAQUA				67.1	8.1	2

* 1.0 lbf/in = 175.1 N/m

TABLE 31. SEAM SHEAR AND PEEL STRENGTH - 80 MIL HDPE (U) - EXTRUSION FILLET WELD FIELD SEAM - SAMPLE 31

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	203.0	18.2	9-2	123.0	20.8	2
WATER 3	198.5	7.6	9	157.3	10.7	2
WATER 6	217.0	18.3	2-6	134.5	28.2	6
WATER 12	216.0	7.4	6	148.8	14.8	2
23° BRINE 3	220.0	7.5	9	156.0	17.1	2
23° BRINE 12	214.8	6.1	2-6	153.2	23.4	2
50° BRINE 3	212.6	9.7	6	101.2	40.3	2
50° BRINE 6	225.0	3.6	6	121.4	30.7	2
50° BRINE 12	218.6	5.9	2	132.5	23.8	2
PHENOL 3	243.0	5.2	5	143.3	29.5	2
PHENOL 6	268.8	9.9	2	167.2	39.6	2
PHENOL 12	219.0	6.7	2	125.3	28.2	2
HCL 3	219.0	6.0	6	77.5	39.5	2
HCL 6	254.7	3.4	9	125.3	35.3	2
HCL 12	213.6	12.9	2	126.1	19.0	2
NAOH 3	256.6	4.0	6	97.2	40.7	2
NAOH 6	261.7	9.1	9-2	136.0	20.8	2
NAOH 12	224.3	20.5	2	145.5	22.2	2
MEK 3	229.0	3.5	4	158.7	6.4	2
MEK 6	262.0	9.3	9-2	125.4	19.2	2
MEK 12	214.9	3.8	2	138.6	26.6	2
MCL 3	268.5	3.9	6	135.8	41.0	2
MCL 6	247.9	6.9	9	153.5	3.3	2
MCL 12	217.1	6.7	2	162.9	13.1	2
FURFURAL 3	205.5	14.8	2	149.3	15.9	2
FURFURAL 6	240.3	3.8	9	161.2	27.4	2
FURFURAL 12	217.8	11.9	2	118.0	47.2	2
H A 4	131.8	68.8	2-6	66.6	34.5	2
H A 8	217.0	7.2	6	148.3	14.6	2
H A 13	212.4	4.1	9	126.9	19.4	2
F/T 10	175.8	4.2	6	124.6	29.9	2
F/T 20	190.4	9.7	9	128.2	19.1	2
F/T 50	209.5	7.5	6	149.3	23.8	2
W/D 10	206.4	3.2	9	151.1	11.5	2
W/D 20	179.8	33.6	2-6	102.9	22.6	2
W/D 50	205.2	7.8	9	173.7	13.9	2
EMMAQUA				--	--	--

* 1.0 lbf/in = 175.1 N/m

TABLE 32. SEAM SHEAR AND PEEL STRENGTH - 80 MIL HDPE (U) - EXTRUSION LAP WELD FIELD SEAM - SAMPLE 32

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	242.0	13.5	9	175.0	20.1	2
WATER 3	241.8	6.8	9	167.4	17.8	2
WATER 6	236.6	15.5	6	159.5	30.2	6
WATER 12	214.5	2.9	6	165.4	10.4	2
23° BRINE 3	245.0	2.8	9	169.8	21.8	2-6
23° BRINE 12	258.0	10.9	6	180.1	14.2	2
50° BRINE 3	260.4	11.5	2-6	171.6	25.2	2
50° BRINE 6	247.5	9.6	6	165.2	11.3	2
50° BRINE 12	240.0	7.2	6	156.4	5.8	2
PHENOL 3	267.0	9.0	6	161.3	42.7	4-6
PHENOL 6	279.8	14.6	6	176.0	32.7	2
PHENOL 12	248.1	4.8	6	153.3	21.5	2
HCL 3	265.0	3.5	6	191.4	19.9	2
HCL 6	285.0	3.0	2	162.7	20.1	2
HCL 12	265.8	29.5	6-2	178.9	8.0	2
NAOH 3	256.0	13.9	2	144.3	20.5	2-4-6
NAOH 6	261.3	13.4	9-2	180.4	15.0	2
NAOH 12	223.2	6.6	2	198.7	105.5	2
MEK 3	247.0	4.6	6	148.2	30.4	4-2
MEK 6	259.8	22.4	2-9	171.1	28.1	2
MEK 12	241.6	18.7	2	179.3	7.8	2
MCL 3	253.3	14.5	6	174.6	21.5	2
MCL 6	258.8	3.2	9	193.5	22.8	2
MCL 12	265.5	9.7	1	147.3	34.3	4-2
FURFURAL 3	263.0	7.5	6	213.0	6.0	2
FURFURAL 6	241.7	12.4	2	176.5	7.0	2
FURFURAL 12	229.8	17.9	2	136.0	33.5	2
H A 4	234.8	9.5	6	141.0	22.8	2
H A 8	223.3	8.7	6	184.6	15.8	2
H A 13	239.8	12.4	9	160.8	24.7	2
F/T 10	219.5	5.5	6	126.1	23.5	2-4-6
F/T 20	218.0	14.2	2-9	147.6	20.6	4-6
F/T 50	239.2	9.7	6	121.2	30.0	4-2
W/D 10	232.6	3.3	2-9	159.0	40.1	2-9
W/D 20	229.9	17.1	6	177.8	8.4	2
W/D 50	246.8	9.6	9-2-6	159.1	15.9	2
EMMAQUA				--	--	--

* 1.0 lbf/in = 175.1 N/m

TABLE 33. SEAM SHEAR AND PEEL STRENGTH - 80 MIL HDPE (U) - THERMAL HOT DUAL WEDGE FIELD SEAM - SAMPLE 33

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	224.0	5.5	9	120.8	4.1	4
WATER 3	220.5	4.8	9	137.8	15.0	4
WATER 6	220.8	6.4	6	106.5	12.4	2
WATER 12	222.0	2.5	2-6	163.0	3.6	2
23° BRINE 3	227.5	1.5	9	112.7	12.5	4
23° BRINE 12	213.8	4.4	6	94.0	20.3	4
50° BRINE 3	221.4	7.1	6	127.7	16.7	2
50° BRINE 6	212.3	0.9	6	96.2	8.2	4-6
50° BRINE 12	226.8	7.9	1-2	104.3	42.5	1-2
PHENOL 3	247.0	7.6	6	150.3	5.9	4
PHENOL 6	228.0	3.4	6-2	181.4	19.4	2
PHENOL 12	219.5	9.0	9-2	149.6	9.9	2
HCL 3	220.0	4.6	6	169.8	6.9	2
HCL 6	243.5	10.6	9	113.7	84.6	4-6
HCL 12	236.8	16.1	2	147.5	16.5	2-3
NAOH 3	231.0	10.5	6	152.7	5.9	2
NAOH 6	233.3	10.1	9	157.9	39.7	2
NAOH 12	217.1	8.9	2-9	144.9	10.7	2
MEK 3	223.5	3.9	6	170.4	4.9	2
MEK 6	231.9	4.2	9-2	178.3	6.0	2
MEK 12	192.5	12.8	2	145.0	7.9	2
MCL 3	225.0	10.8	6	168.4	9.5	2
MCL 6	229.7	9.3	9	177.3	8.5	6
MCL 12	212.1	4.4	2	158.1	11.5	2
FURFURAL 3	224.0	6.2	6	169.2	8.1	2
FURFURAL 6	232.9	7.3	9	170.9	9.0	2
FURFURAL 12	220.9	8.7	2	157.9	5.2	2
H A 4	215.5	4.5	6	112.4	25.4	4
H A 8	225.6	5.2	6	86.6	16.8	4
H A 13	221.2	3.3	9	120.6	12.5	4
F/T 10	196.5	2.9	6	102.8	2.2	4-6
F/T 20	206.6	8.1	9	103.2	3.8	2-4
F/T 50	207.0	5.3	6	119.8	18.1	4-6
W/D 10	200.8	8.9	9-2	118.6	15.3	2
W/D 20	200.2	1.7	6	122.4	25.4	4-6
W/D 50	224.6	5.4	9	100.2	19.4	4-2
EMMAQUA				108.0	3.5	2-6

* 1.0 lbf/in = 175.1 N/m

TABLE 34. SEAM SHEAR AND PEEL STRENGTH - 30 MIL LLDPE (U) - THERMAL HOT WEDGE FIELD SEAM - SAMPLE 34

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	62.5	0.6	9	60.6	1.5	9
WATER 3	78.6	0.5	9	31.0	1.9	4
WATER 6	80.9	1.3	6	35.0	6.6	4
WATER 12	79.0	2.9	6	29.6	12.9	4
23° BRINE 3	79.9	0.4	9	24.1	4.6	4
23° BRINE 12	77.0	1.1	6	34.0	11.3	4
50° BRINE 3	78.8	3.1	6	26.1	2.7	4
50° BRINE 6	77.3	1.2	6	20.0	6.6	4
50° BRINE 12	82.2	3.4	2-9	18.7	2.6	4
PHENOL 3	66.0	2.7	6	70.1	3.0	6
PHENOL 6	61.3	0.6	6	61.6	2.1	2
PHENOL 12	60.3	3.9	2	58.9	3.6	2
HCL 3	66.6	0.9	6	64.8	1.9	6
HCL 6	64.7	4.3	6	57.4	1.4	2
HCL 12	69.3	4.0	2	59.0	4.1	2
NAOH 3	67.8	1.1	2	65.1	2.3	2
NAOH 6	63.3	5.2	6	65.3	4.3	2
NAOH 12	66.8	2.5	2	55.8	5.5	2
MEK 3	61.0	2.3	6	59.7	2.0	6
MEK 6	35.7	1.6	6	72.9	2.8	2
MEK 12	62.3	2.2	2	58.2	2.5	2
MCL 3	67.0	0.4	6	64.0	3.1	6
MCL 6	65.3	1.0	9	72.8	2.7	6
MCL 12	60.1	4.1	2	59.3	1.3	2
FURFURAL 3	59.0	1.7	6	64.2	4.8	6
FURFURAL 6	67.8	4.1	6	65.4	2.3	2
FURFURAL 12	56.7	4.5	2	32.4	5.0	4
H A 4	78.9	2.7	6	18.2	2.7	4
H A 8	78.8	1.7	6	11.3	3.3	4
H A 13	78.1	3.1	9	16.0	4.6	4
F/T 10	75.9	2.2	6	23.0	5.1	4
F/T 20	73.4	2.0	9	12.0	3.9	4
F/T 50	74.4	2.4	6	16.9	8.7	4
W/D 10	77.7	3.6	9	38.1	12.6	4
W/D 20	75.3	1.7	6	20.0	8.0	4
W/D 50	75.8	1.1	9	22.1	4.1	4
EMMAQUA				60.5	5.5	1-2

* 1.0 lbf/in = 175.1 N/m

TABLE 35. SEAM SHEAR AND PEEL STRENGTH - 30 MIL PVC (U) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 35

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	47.7	3.8	2	15.7	3.7	3
WATER 3	43.7	5.7	2	15.4	2.7	3
WATER 6	48.6	3.1	2	17.6	4.0	3
WATER 12	51.3	3.7	2	15.4	2.3	3
23° BRINE 3	44.8	2.6	2	15.1	2.7	3
23° BRINE 12	49.1	1.9	2	13.6	2.1	3
50° BRINE 3	50.9	3.1	2	15.9	3.8	3
50° BRINE 6	50.2	4.6	2	16.5	2.7	3
50° BRINE 12	48.5	7.5	2-1	13.5	2.5	3
PHENOL 3	60.5	2.1	2	26.9	3.7	3
PHENOL 6	57.0	1.3	2	29.3	7.0	3-6
PHENOL 12	85.4	4.1	6	19.1	10.1	3
HCL 3	52.8	1.2	1-2	12.3	2.3	3
HCL 6	53.0	0.7	2	20.6	4.9	3
HCL 12	51.0	2.9	2	16.0	0.4	3
NAOH 3	81.4	1.1	2	34.7	7.7	3
NAOH 6	87.3	1.8	2-6	35.8	7.1	3-6
NAOH 12	53.1	6.4	6	19.0	2.3	3
MEK 3	49.4	6.4	2	10.1	2.4	3
MEK 6	46.0	5.0	1-2	12.3	0.6	3
MEK 12	48.9	4.3	2	18.5	1.9	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	66.0	1.5	1-2	13.3	1.9	3
FURFURAL 6	41.2	0.7	2	16.2	4.6	3
FURFURAL 12	49.9	3.0	1	30.7	7.6	3
H A 4	50.4	2.9	2	21.8	1.3	3
H A 8	53.9	3.6	2	18.3	7.8	3-6
H A 13	52.0	3.1	2	23.5	1.1	3
F/T 10	48.0	3.1	2	13.5	1.8	3
F/T 20	53.2	3.5	2	17.2	1.8	3-6
F/T 50	51.1	4.6	2-1	15.5	0.6	3
W/D 10	48.2	2.5	2	14.8	0.7	3
W/D 20	50.4	1.5	2-1	18.8	2.4	3
W/D 50	46.8	3.9	2-1-3	11.3	2.5	3
EMMAQUA				21.6	2.4	3

* 1.0 lbf/in = 175.1 N/m

TABLE 36. SEAM SHEAR AND PEEL STRENGTH - 30 MIL PVC (U) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 36

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	53.2	1.0	2	19.2	0.6	3
WATER 3	54.2	2.6	2	18.3	3.6	3
WATER 6	59.9	1.2	2	21.9	2.8	3
WATER 12	60.9	1.6	2	22.4	2.1	3
23° BRINE 3	45.5	1.7	2	19.1	3.4	3
23° BRINE 12	51.1	5.2	2	19.3	2.4	3
50° BRINE 3	53.7	2.0	2	24.8	1.6	3
50° BRINE 6	57.3	2.6	2	22.5	3.0	3-6
50° BRINE 12	56.6	1.7	2	22.3	3.0	3
PHENOL 3	64.5	2.6	6	13.7	6.7	3
PHENOL 6	70.3	3.6	1-2	37.9	2.1	6
PHENOL 12	59.4	8.2	3	16.7	7.1	3
HCL 3	58.8	1.5	1-2	21.5	4.7	3
HCL 6	57.0	3.5	2	25.3	3.2	3-6
HCL 12	58.3	3.0	2	28.2	2.3	3
NAOH 3	78.8	2.0	6-2	27.6	3.4	3-4
NAOH 6	71.3	4.0	1	34.4	6.1	3
NAOH 12	73.9	1.7	1	47.9	7.2	3-6
MEK 3	59.4	3.1	2	18.5	4.8	3
MEK 6	54.8	1.7	2-1	24.2	8.0	3
MEK 12	55.8	4.0	2	15.0	1.5	3
MCL 3	—	—	—	—	—	—
MCL 6	—	—	—	—	—	—
MCL 12	—	—	—	—	—	—
FURFURAL 3	56.7	2.6	2	8.8	5.2	3
FURFURAL 6	38.9	3.2	1	14.5	3.9	3
FURFURAL 12	60.7	4.2	2	28.4	4.6	3
H A 4	59.7	4.0	2	23.8	2.9	3-6
H A 8	53.2	3.8	6-2	24.7	2.8	3
H A 13	56.9	4.3	2	25.1	1.1	3-6
F/T 10	55.1	2.4	2	22.8	2.3	3-6
F/T 20	57.2	2.9	2	22.7	1.5	3
F/T 50	51.8	3.0	2	21.8	2.5	3-6
W/D 10	58.8	4.0	2-1	21.9	1.9	3-6
W/D 20	54.5	6.2	2	21.0	2.8	3
W/D 50	60.3	2.1	2	24.4	3.4	3
EMMAQUA				31.3	4.2	6-3

* 1.0 lbf/in = 175.1 N/m

TABLE 37. SEAM SHEAR AND PEEL STRENGTH - 30 MIL PVC (U) - SOLVENT ADHESIVE FIELD SEAM - SAMPLE 37

EXPOSURE	SHEAR lbf/in width*	STANDARD DEVIATION	FAILURE MODE	PEEL lbf/in width*	STANDARD DEVIATION	FAILURE MODE
ORIGINAL	59.6	1.5	2	24.8	2.5	3
WATER 3	67.1	3.6	2	25.0	1.7	3
WATER 6	60.5	4.4	2	24.8	2.0	4-6
WATER 12	66.7	2.8	1-2	25.0	3.3	3-6
23° BRINE 3	64.9	2.8	2	23.7	2.1	3
23° BRINE 12	62.3	2.0	2	28.0	3.9	3-6
50° BRINE 3	62.1	3.1	2	32.1	1.6	3-6
50° BRINE 6	57.3	4.2	2	25.7	3.7	3-6
50° BRINE 12	64.2	4.0	2-1	25.7	2.6	3
PHENOL 3	66.4	1.6	2-5	19.0	6.5	3
PHENOL 6	60.8	3.2	1-2	32.2	5.0	3
PHENOL 12	85.4	6.9	2	30.8	6.6	3
HCL 3	62.6	2.3	2	30.5	2.7	4
HCL 6	54.2	6.0	2	23.7	10.0	3
HCL 12	66.5	4.1	2	23.9	3.1	3
NAOH 3	76.0	3.5	2	31.9	2.3	3
NAOH 6	83.2	5.5	2	36.9	3.6	3-6
NAOH 12	88.4	10.9	2	46.6	6.5	3
MEK 3	67.5	0.0	1-2	29.5	2.9	4
MEK 6	55.5	4.1	2	23.4	1.6	3
MEK 12	57.8	4.0	2	19.8	5.9	3
MCL 3	--	--	--	--	--	--
MCL 6	--	--	--	--	--	--
MCL 12	--	--	--	--	--	--
FURFURAL 3	66.0	3.0	2	19.7	2.6	3
FURFURAL 6	48.4	2.8	2	19.8	3.7	3
FURFURAL 12	66.2	10.7	2	41.0	1.8	3
H A 4	57.4	2.3	2	23.1	12.9	2-3-6
H A 8	64.6	3.3	2	29.1	2.8	3-6
H A 13	65.3	6.2	2	22.5	5.6	3-6
F/T 10	59.8	3.6	2	25.7	3.0	3
F/T 20	68.9	3.1	2	35.2	1.4	6-2
F/T 50	57.5	3.7	2	26.7	1.4	3-6
W/D 10	64.0	3.5	2	34.1	5.2	6-2
W/D 20	58.1	1.2	2	18.1	5.9	3
W/D 50	61.3	6.5	2	26.4	4.1	3-6
EMMAQUA				33.2	4.6	2

* 1.0 lbf/in = 175.1 N/m

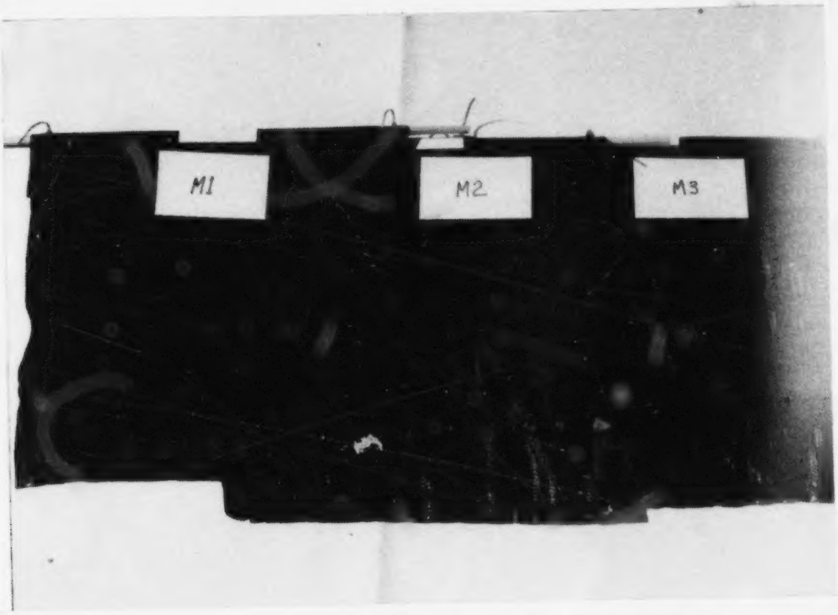


Figure 1. Appearance of CPE Sample 1 (M1), and CSPE Samples 32 (M2) and 22 (M3) after 12 months in 10 percent phenol. Note blistering of samples.

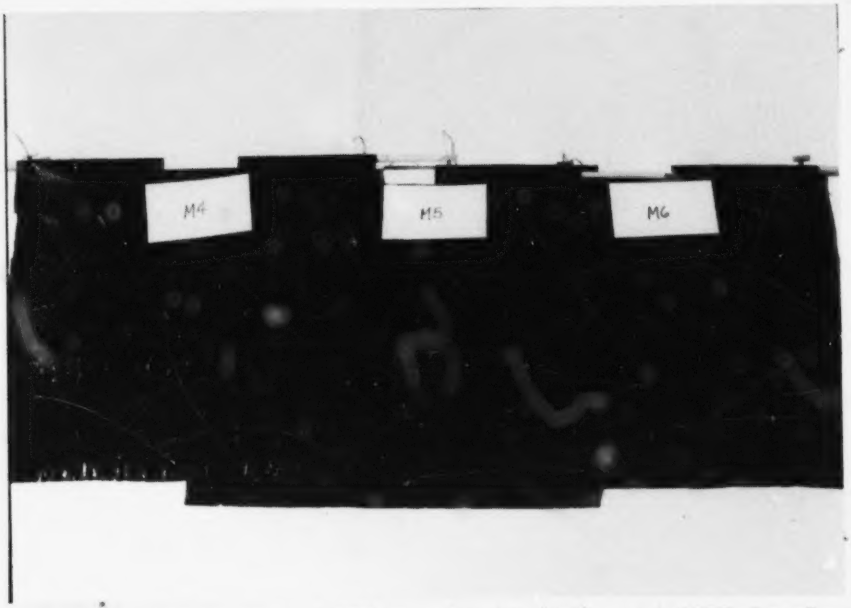


Figure 2 Appearance of CPE Sample 17 (M4), and CSPE Samples 3 (M5) and 19 (M6) after 12 months in 10 percent phenol.

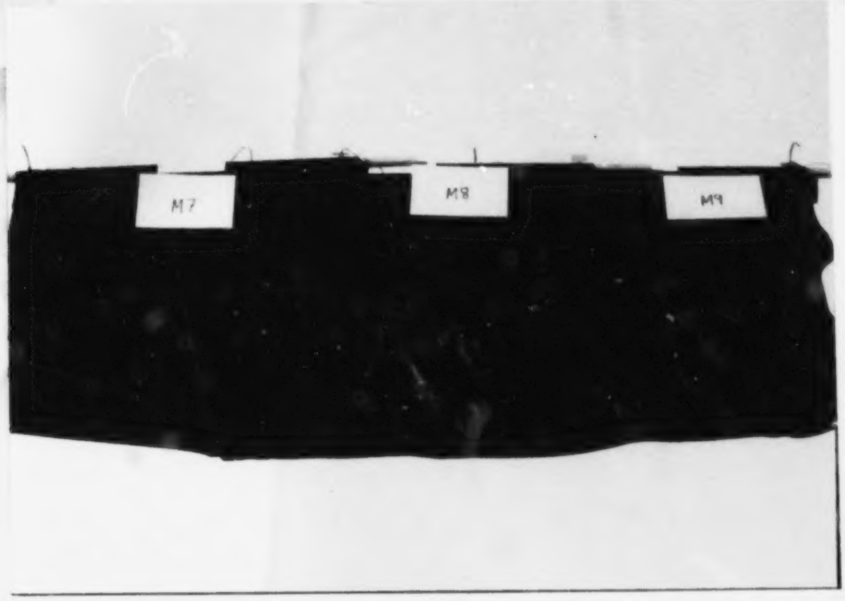


Figure 3. Appearance of CSPE Samples 4 (M7), 20 (M8) and 5 (M9) after 12 months in 10 percent phenol.

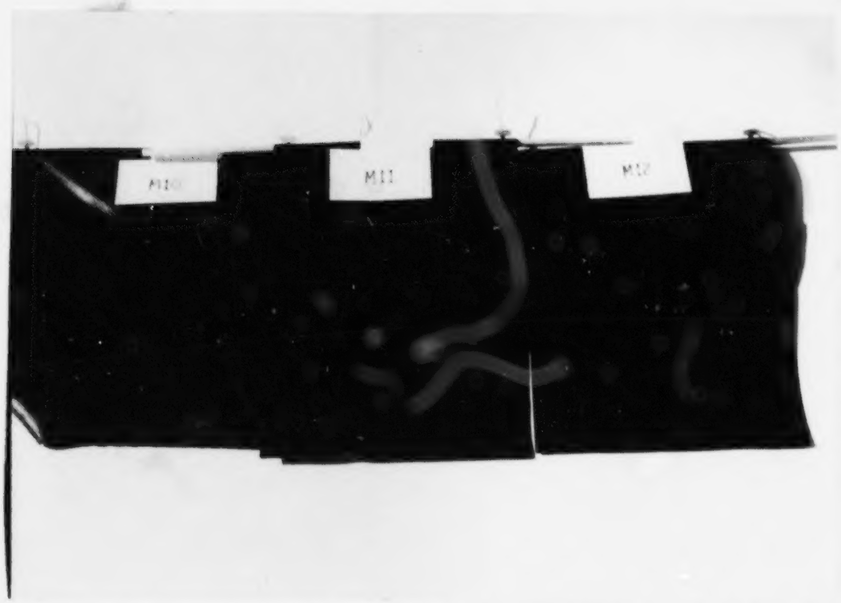


Figure 4. Appearance of CSPE Sample 21 (M10), and LLDPE Samples 13 (M11) and 34 after 12 months in 10 percent phenol.

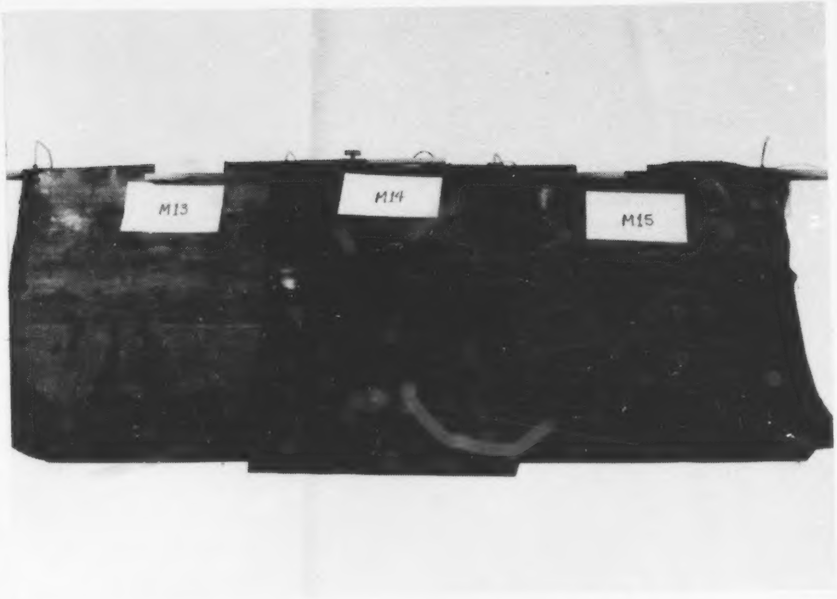


Figure 5. Appearance of EPDM Samples 10 (M13) and 17 (M15), and HDPE Sample 30 (M14) after 12 months in 10 percent phenol.

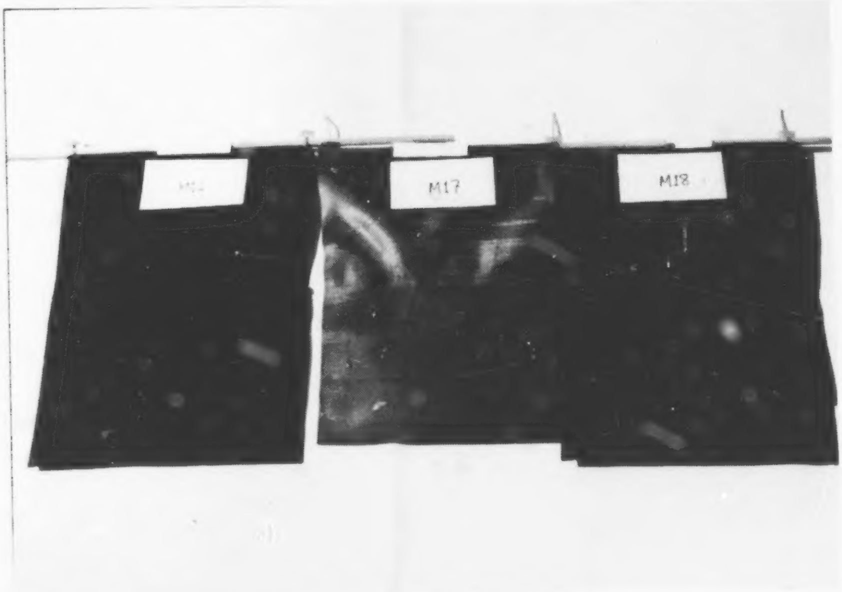


Figure 6. Appearance of HDPE Samples 31 (M16) and 32 (M18), and PVC Sample 14 (M17) after 12 months in 10 percent phenol.

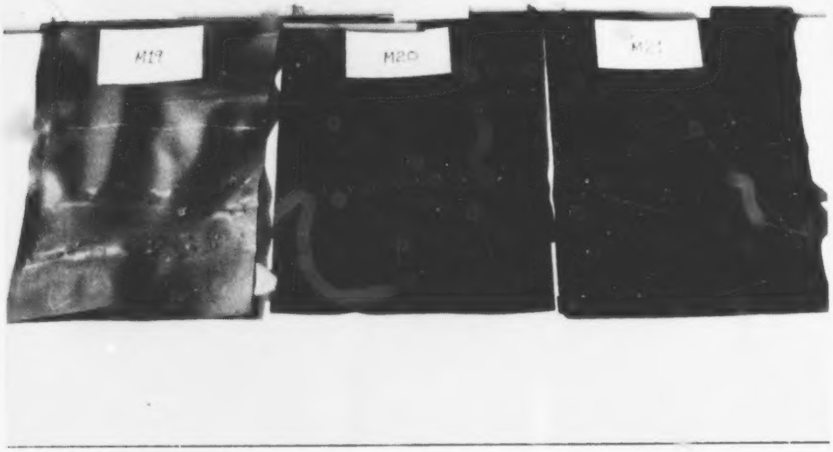


Figure 7. Appearance of PVC Sample 35 (M19), HDPE Sample 33 (M20) and CPE Sample 11 (M21) after 12 months in 10 percent phenol.

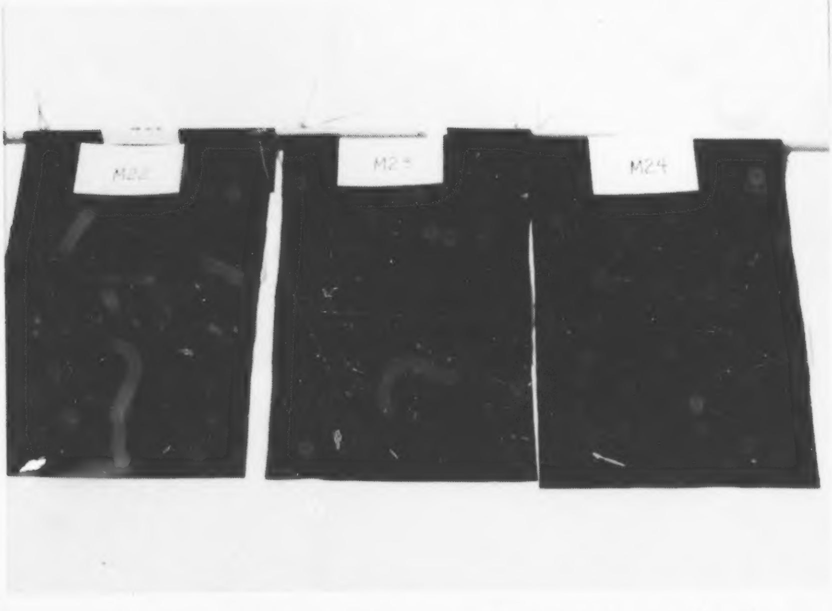


Figure 8. Appearance of CPE Samples 28 (M22), 12 (M23) and 29 (M24) after 12 months in 10 percent phenol. Note blistering of Sample 28.

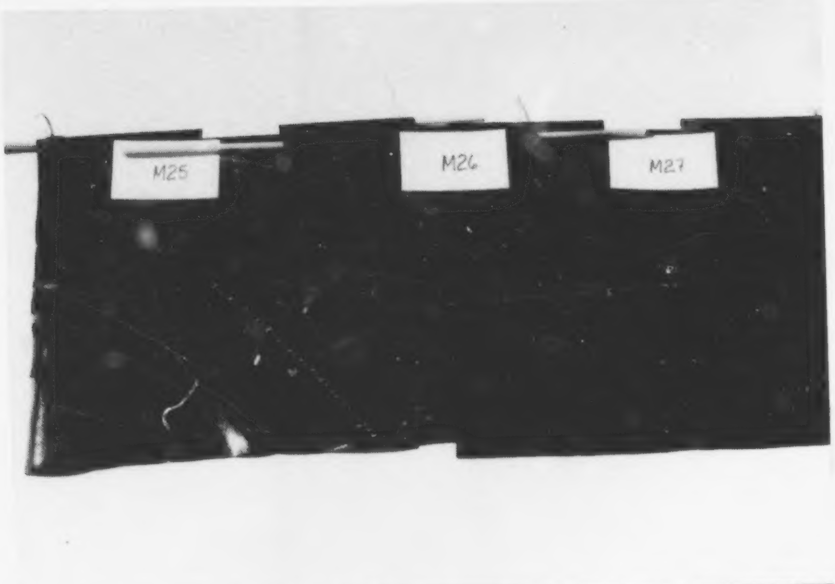


Figure 9. Appearance of CSPE Samples 7 (M27) and 8 (M25), and PVC Sample 15 (M26) after 12 months in 10 percent phenol.

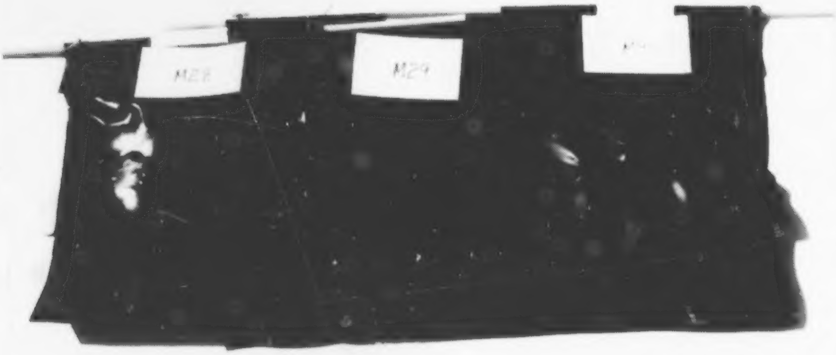


Figure 10. Appearance of PVC Samples 36 (M28) and 16 (M30), and CSPE Sample 23 (M29) after 12 months in 10 percent phenol.

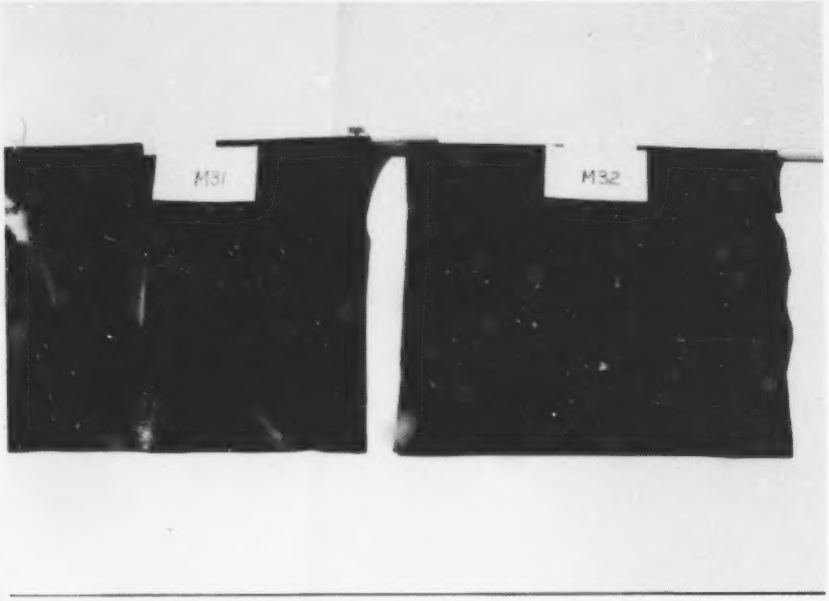


Figure 11. Appearance CSPE Sample 24 (M31) and CPE Sample 2 (M32) after 12 months of immersion in 10 percent phenol.

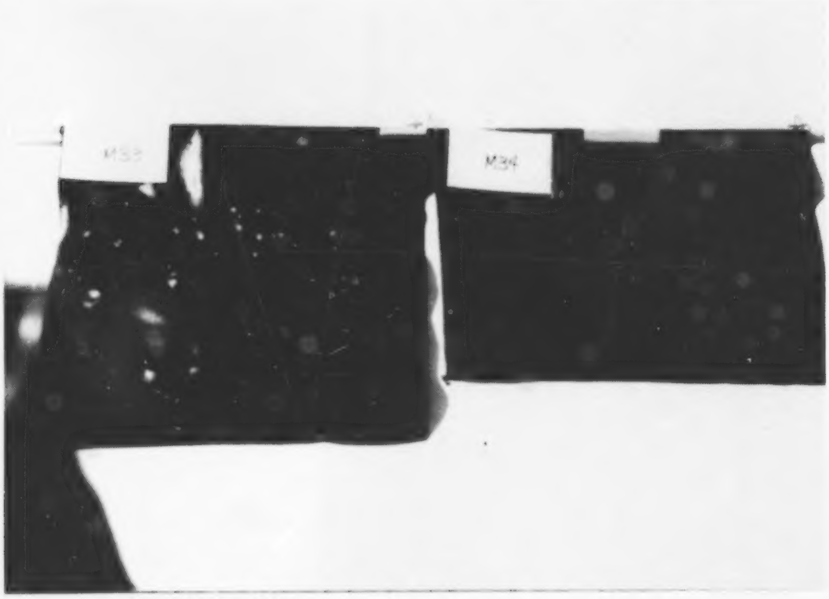


Figure 12. Appearance of CPE Sample 18 (M33) and CSPE Sample 25 (M34) after 12 months of immersion in 10 percent phenol.

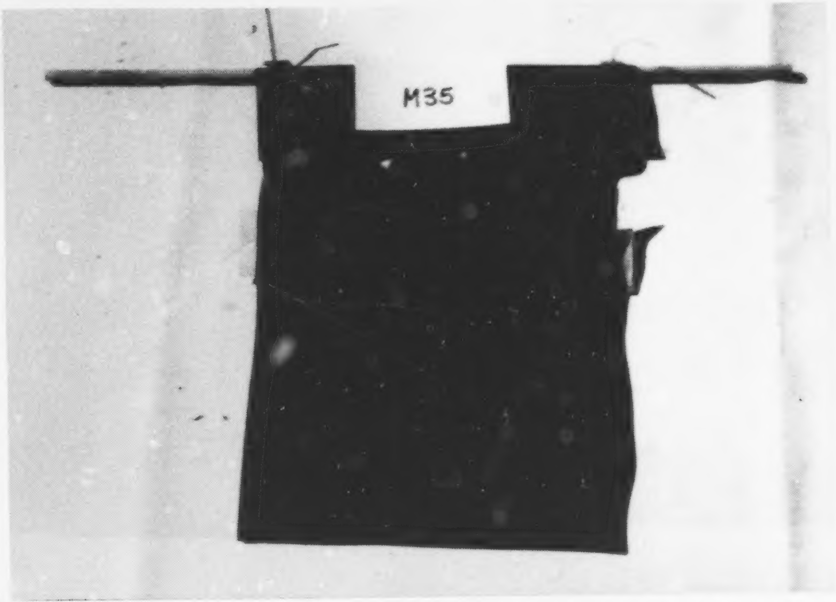


Figure 13. Appearance of PVC Sample 37 (M35) after 12 months of immersion in 10 percent phenol. Note blistering of the material.

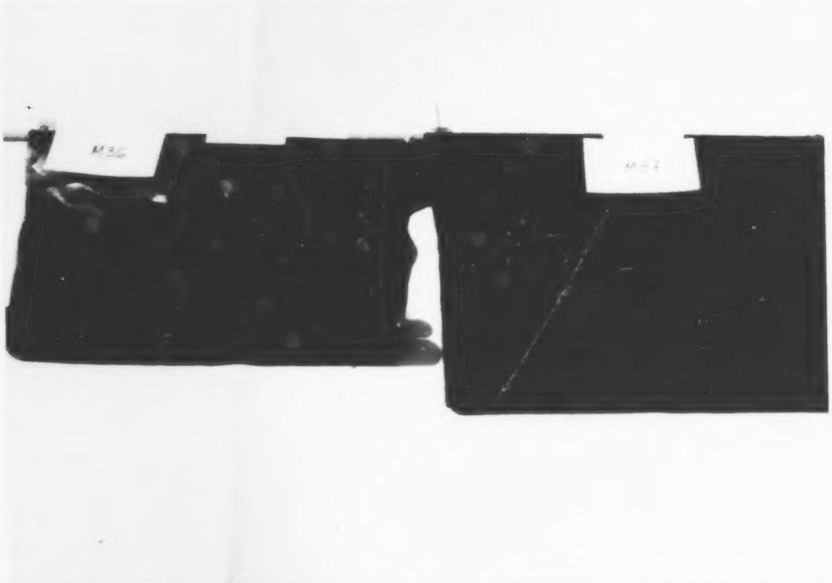


Figure 14. Appearance of E1A Samples 9 (M36) and 26 (M37) after 12 months of immersion in 10 percent phenol. Note curling of the material.

Figure 15. Appearance of CPE Sample 1 (N1), and CSPE Samples 6 (N2) and 22 (N3) after 12 months in 10 percent hydrochloric acid.

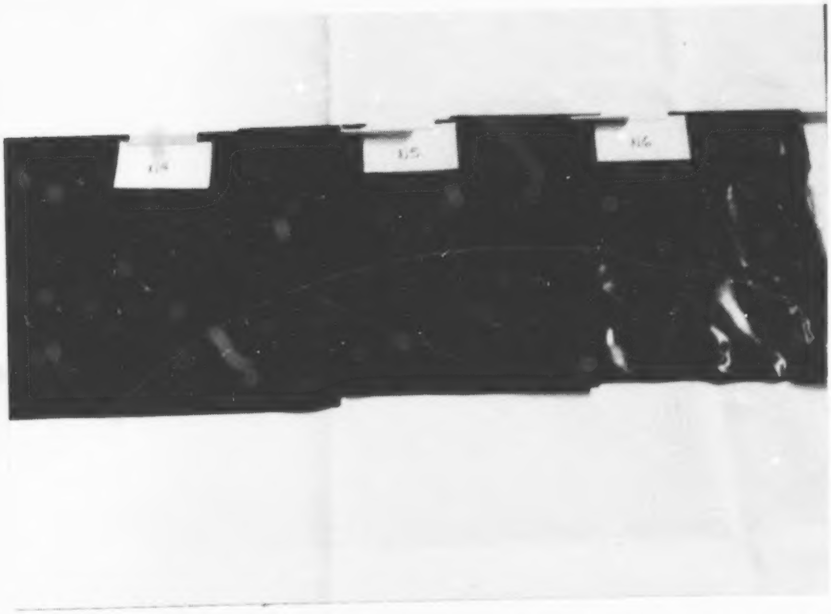


Figure 16. Appearance of CPE Sample 17 (N4), and CSPE Samples 3 (N5) and 19 (N6) after 12 months in 10 percent hydrochloric acid.

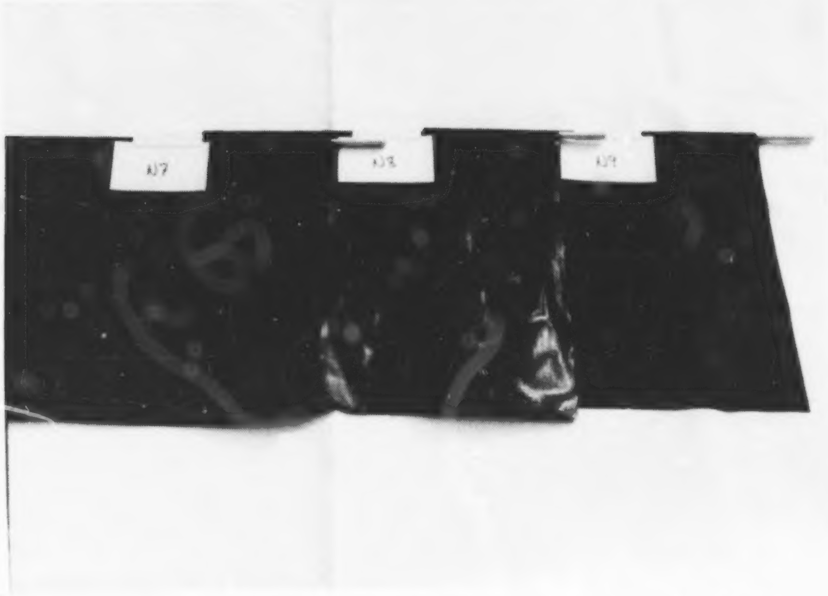


Figure 17. Appearance of CSPE Samples 4 (N7), 20 (N8) and 5 (N9) after 12 months in 10 percent hydrochloric acid.

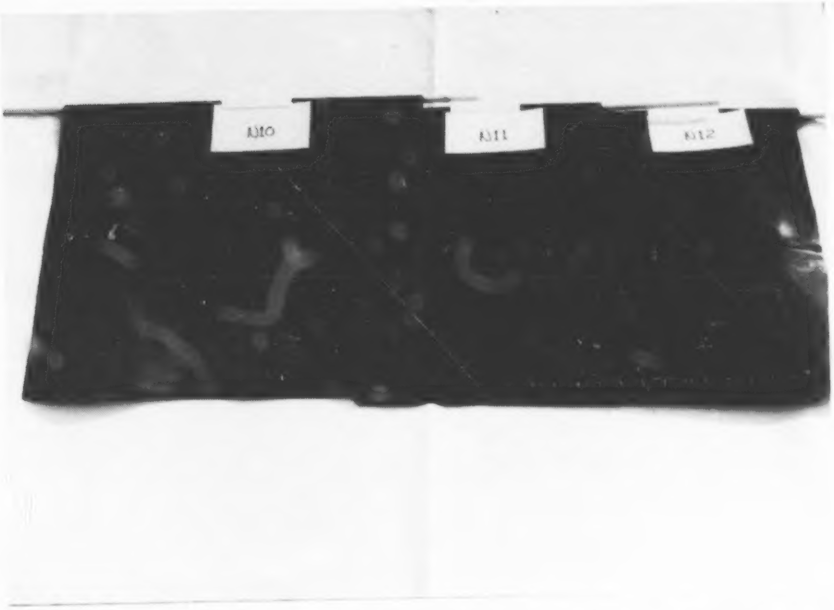


Figure 18. Appearance of CSPE Samples 21 (N10) and 34 (N12), and LLDPE Sample 13 (N11) after 12 months in 10 percent hydrochloric acid.

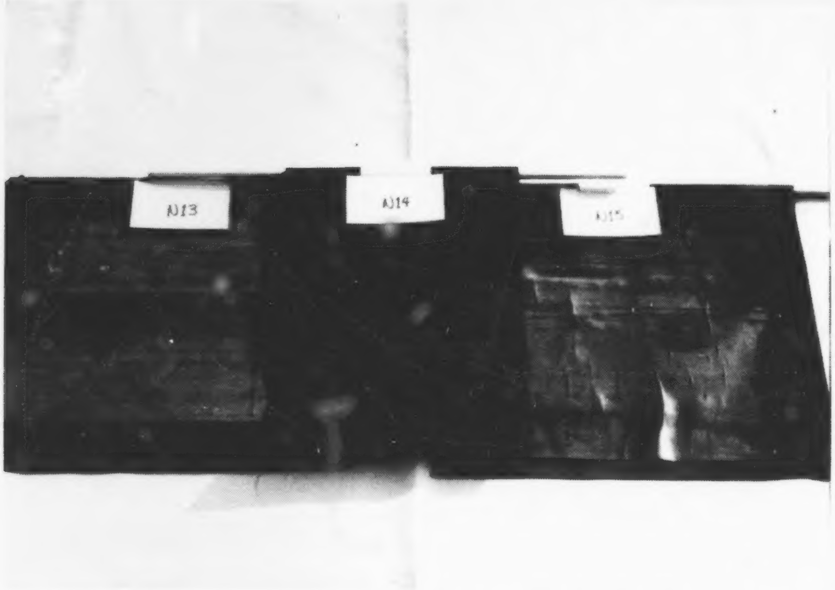


Figure 19. Appearance of EPDM Samples 10 (N13) and 27 (N15), and HDPE Sample 30 (N14) after 12 months in 10 percent hydrochloric acid.

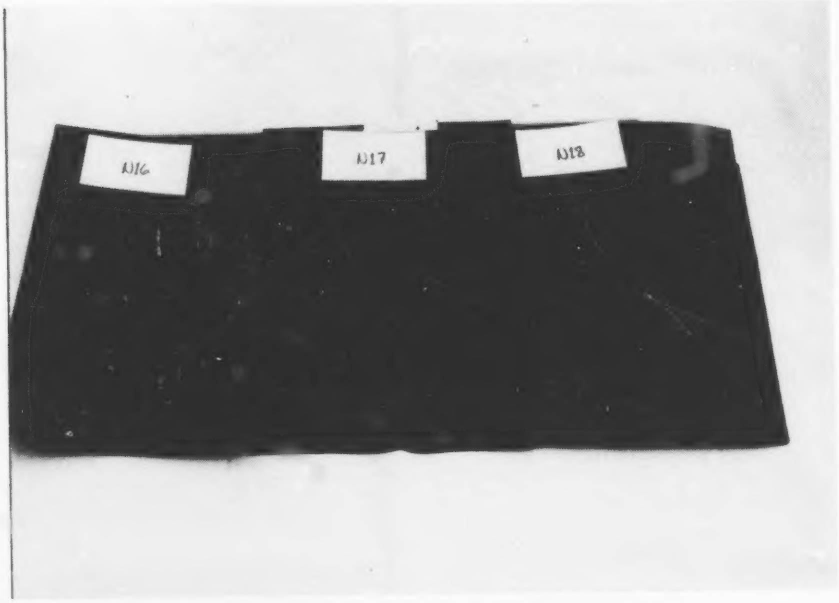


Figure 20. Appearance of HDPE Samples 31 (N16) and 32 (N18), and PVC Sample 14 (N17) after 12 months in 10 percent hydrochloric acid.

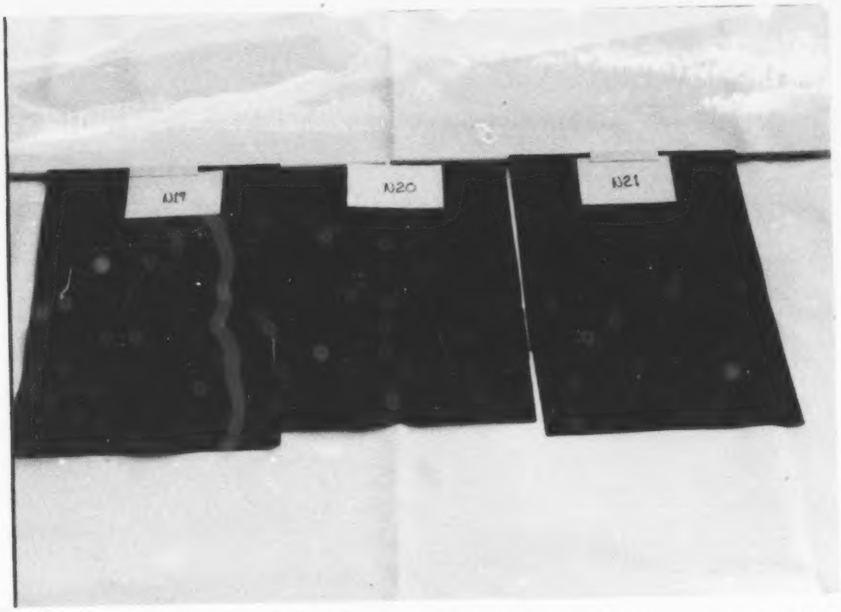


Figure 21. Appearance of PVC Sample 35 (N19), HDPE Sample 33 (N20) and CPE Sample 11 (N21) after 12 months in 10 percent hydrochloric acid.

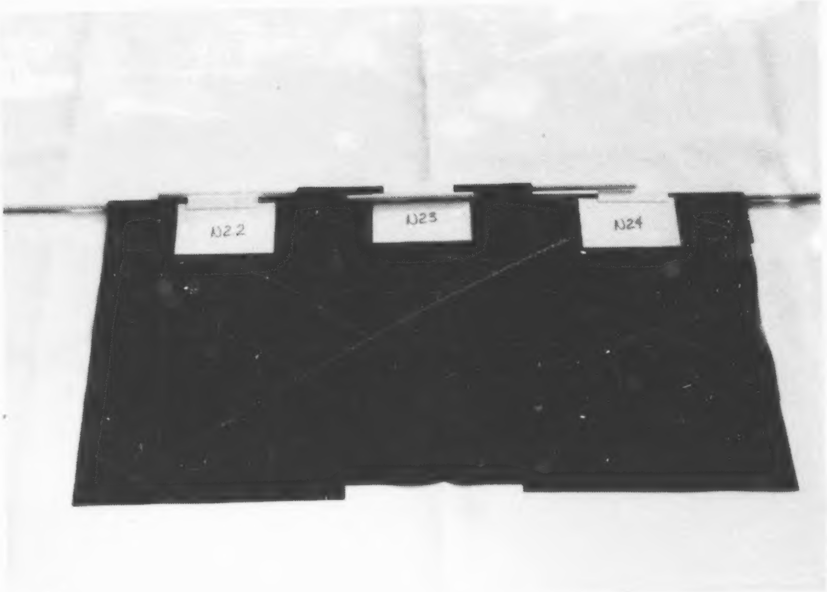


Figure 22. Appearance of CPE Samples 28 (N22), 12 (N23) and 29 (N24) after 12 months in 10 percent hydrochloric acid.

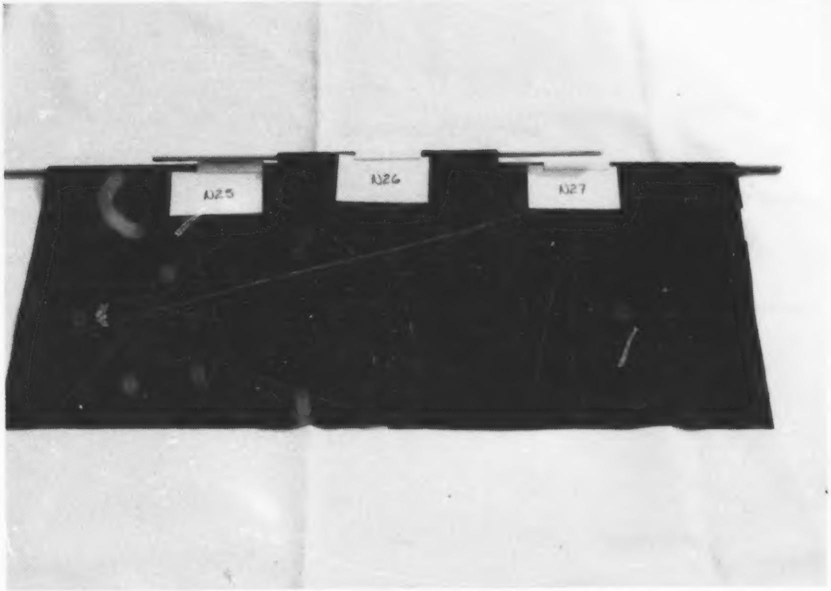


Figure 23. Appearance of CSPE Sample 8 (N25) and & (N27), and PVC Sample (N26) after 12 months in 10 percent hydrochloric acid.

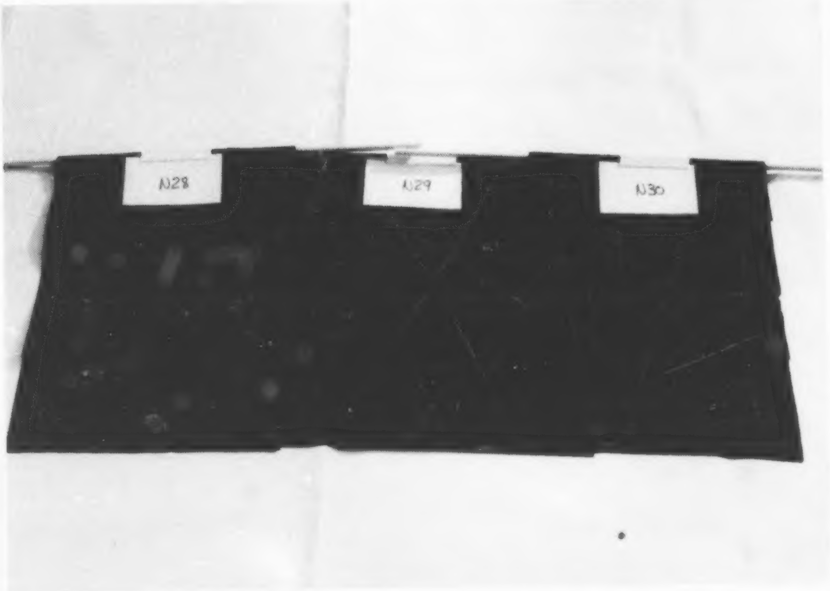


Figure 24. Appearance of PVC Sample 26 (N28), CSPE Sample 23 (N29) and PVC/CPE Sample 16 (N30) after 12 months in 10 percent hydrochloric acid.

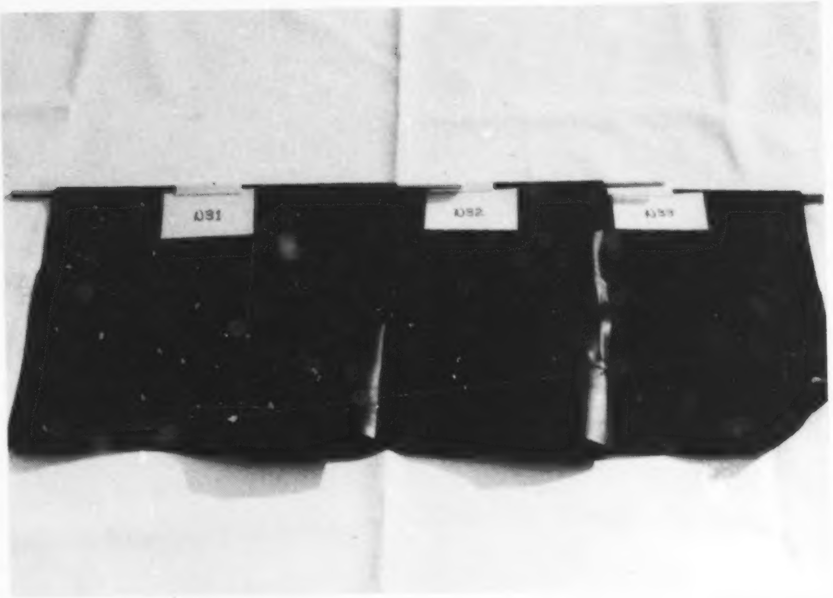


Figure 25. Appearance of CSPE Sample 24 (N31), and CPE Samples 2 (N32) and 18 (N33) after 12 months in 10 percent hydrochloric acid.

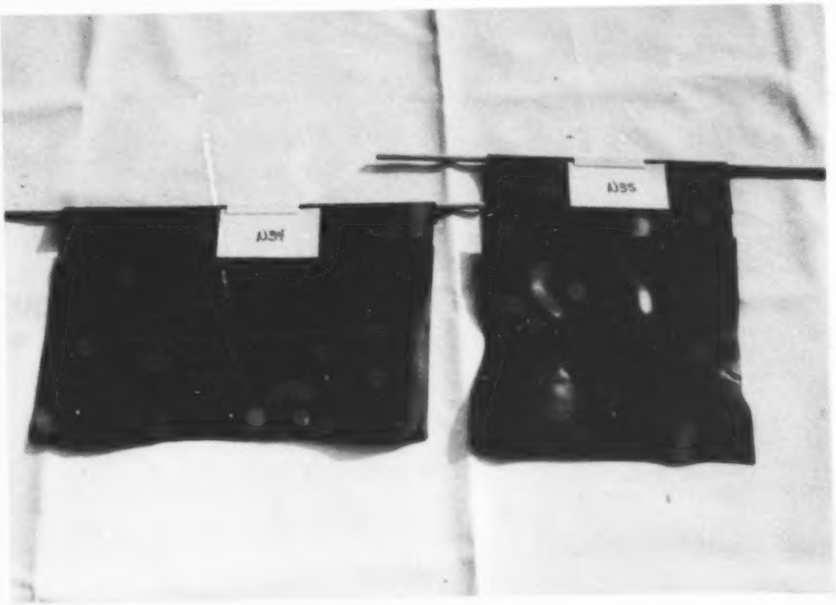


Figure 26. Appearance of CSPE Sample 25 (N34) and PVC Sample 37 (N35) after 12 months in 10 percent hydrochloric acid.

Reproduced from
best available copy.

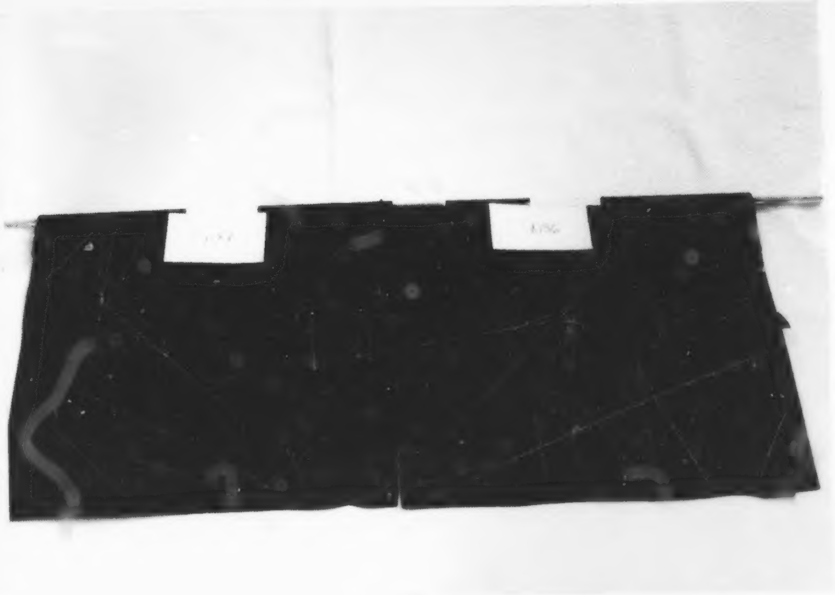


Figure 27. Appearance of E1A Samples 9 (N36) and 26 (N37) after 12 months in 10 percent hydrochloric acid

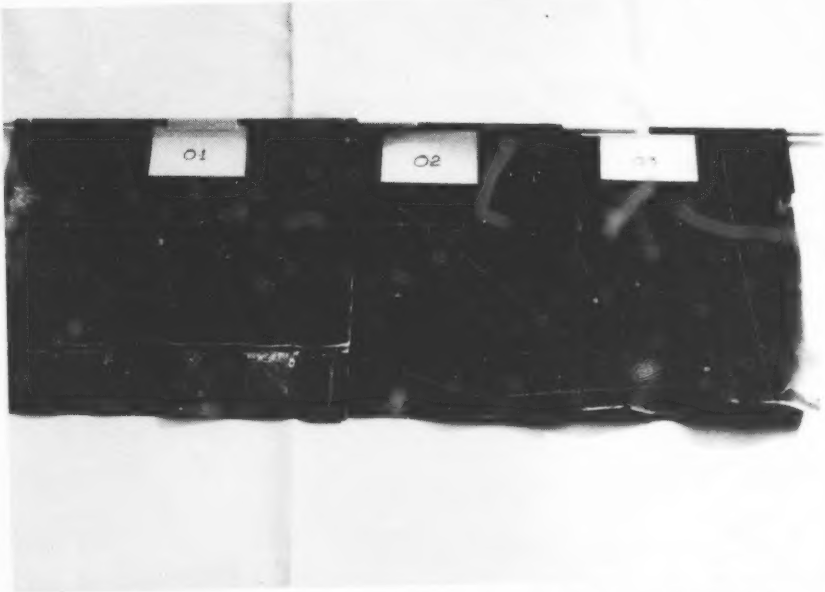


Figure 28. Appearance of CPE Sample 1 (01), and CSPE Samples 6 (02) and 22 (03) after 12 months in 10 percent sodium hydroxide.

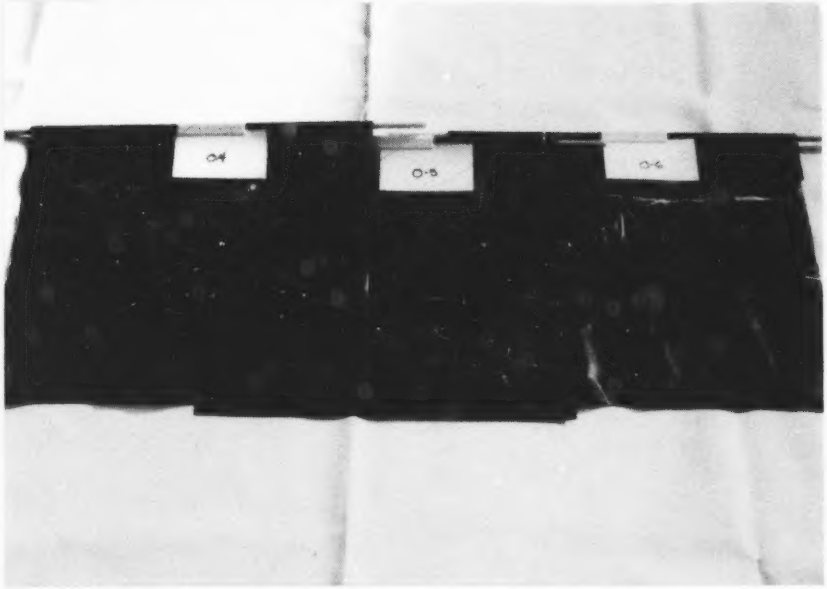


Figure 29. Appearance of CPE Sample 17 (04), and CSPE Samples 3 (05) and 19 (06) after 12 months in 10 percent sodium hydroxide.

Figure 30. Appearance of CSPE Samples 4 (07), 20 (08) and 5 (09) after 12 months in 10 percent sodium hydroxide.

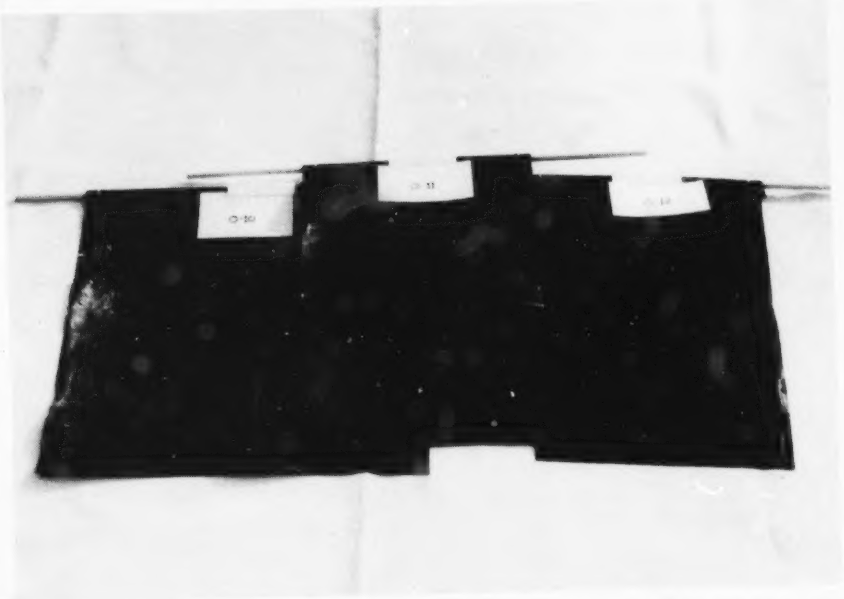


Figure 31. Appearance of CSPE Samples 21 (010) and 34 (012), and LLDPE Sample 13 (011) after 12 months in 10 percent sodium hydroxide.

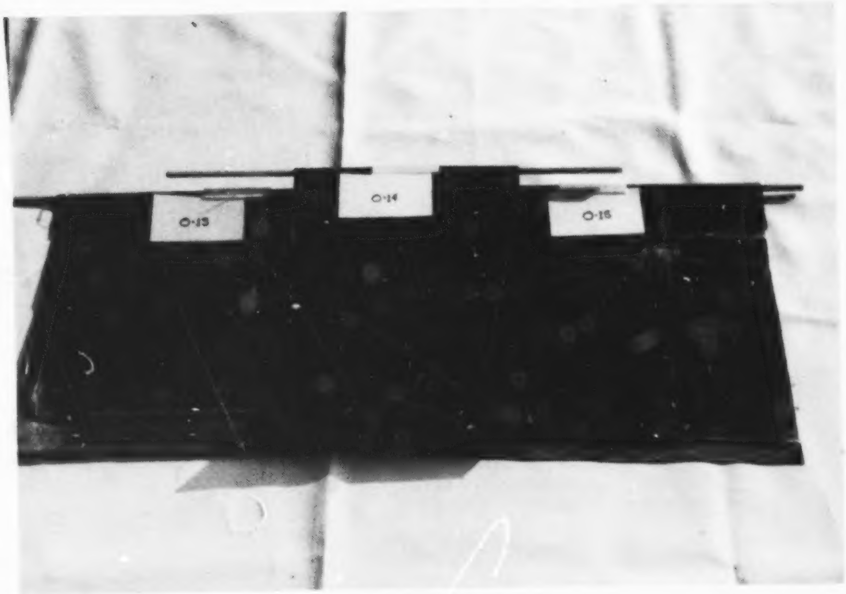


Figure 32. Appearance of EPDM Samples 21 (013) and 27 (015), and HDPE Sample 30 (014) after 12 months in 10 percent sodium hydroxide.

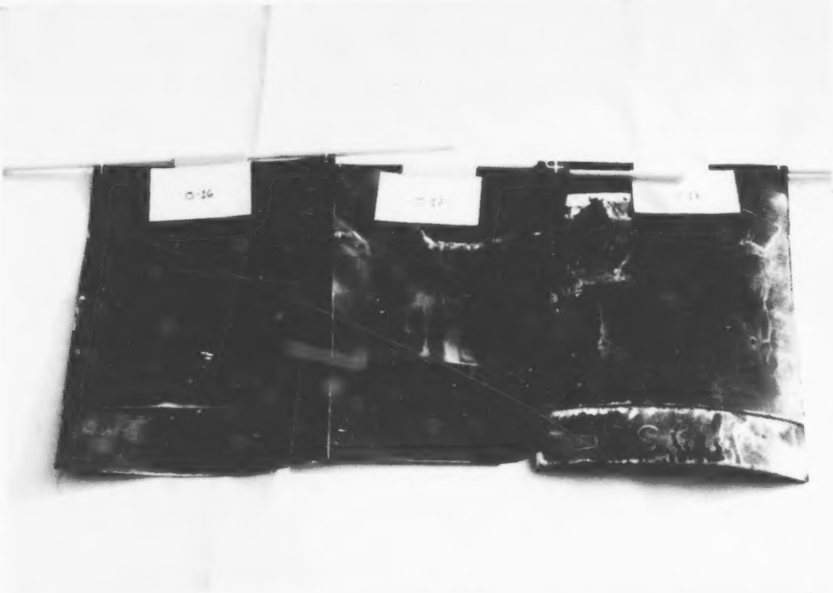


Figure 33. Appearance of HDPE Sample 31 (016) and 32 (018), and PVC Sample 14 (017) after 12 months in 10 percent sodium hydroxide.

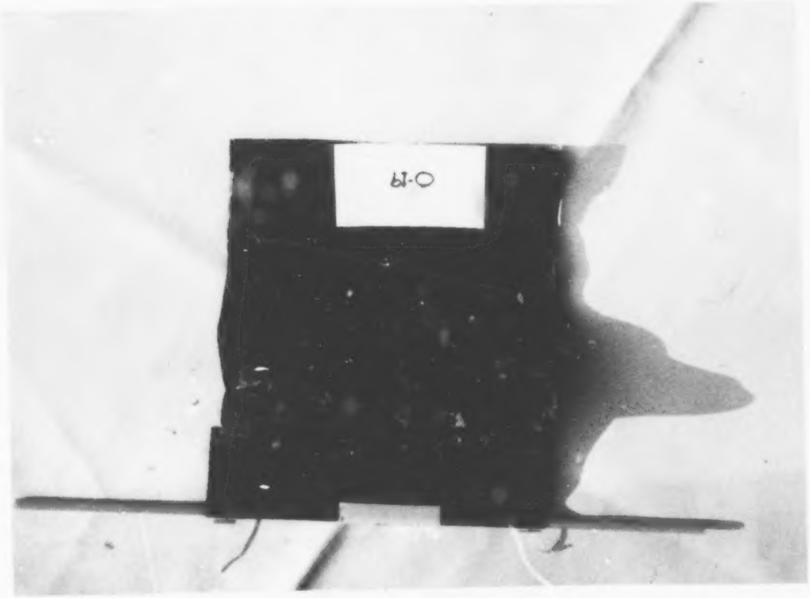


Figure 34. Appearance of PVC Sample 35 (019) after 12 months in 10 percent sodium hydroxide. The exposure caused considerable stiffening of the material.

Reproduced from
best available copy.

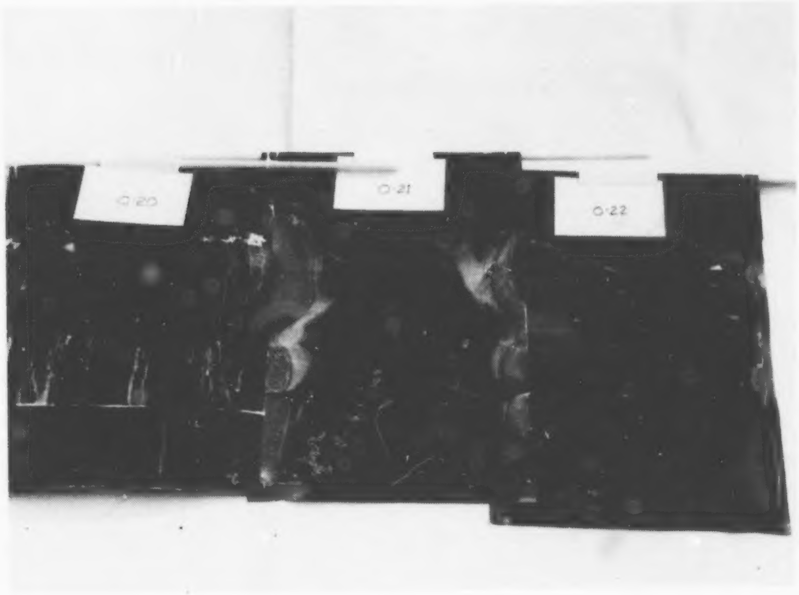


Figure 35. Appearance of HDPE Sample 33 (020), and CPE Samples 11 (021) and 28 (022) after 12 months in 10 percent sodium hydroxide.

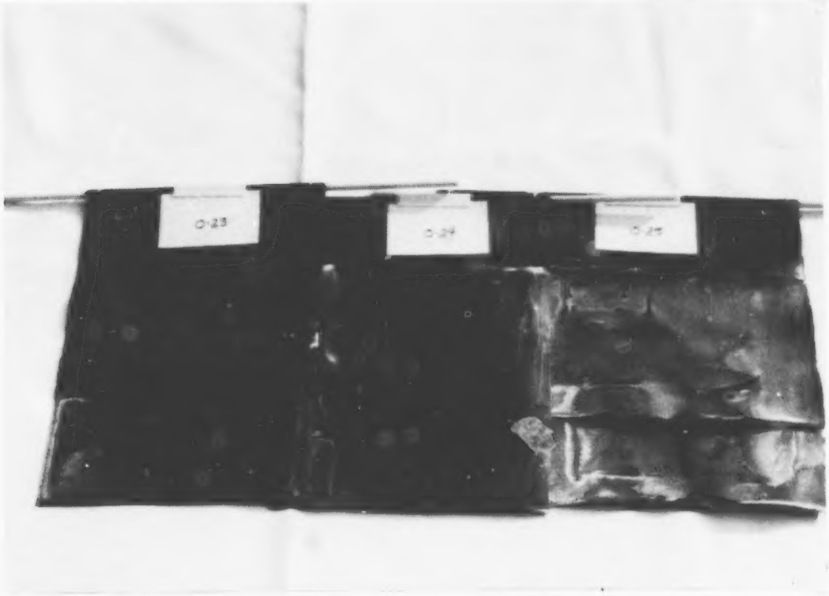


Figure 36. Appearance of CPE Samples 12 (023) and 29 (024), and CSPE Sample 8 (025) after 12 months in 10 percent sodium hyroxide.

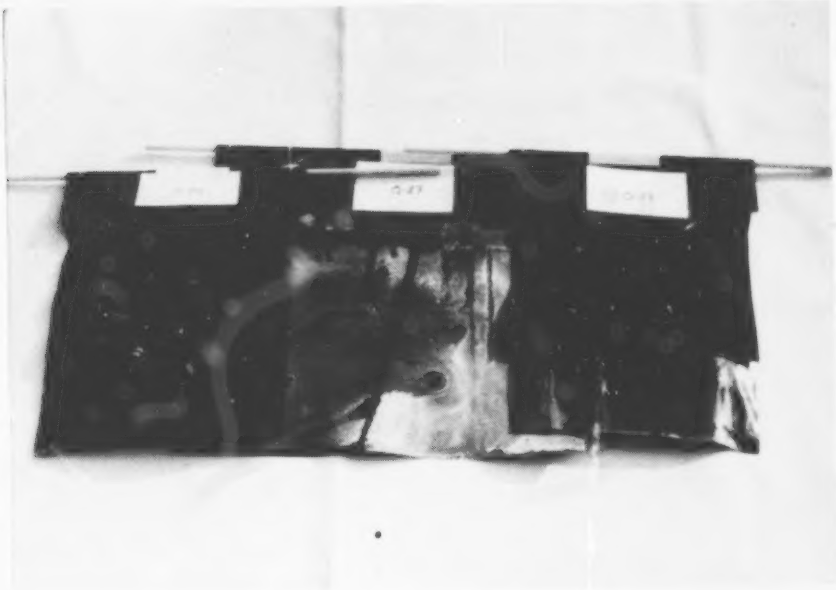


Figure 37. Appearance of PVC Samples 15 (026) and 36 (028), and CSPE Sample 23 (027) after 12 months in 10 percent sodium hydroxide.

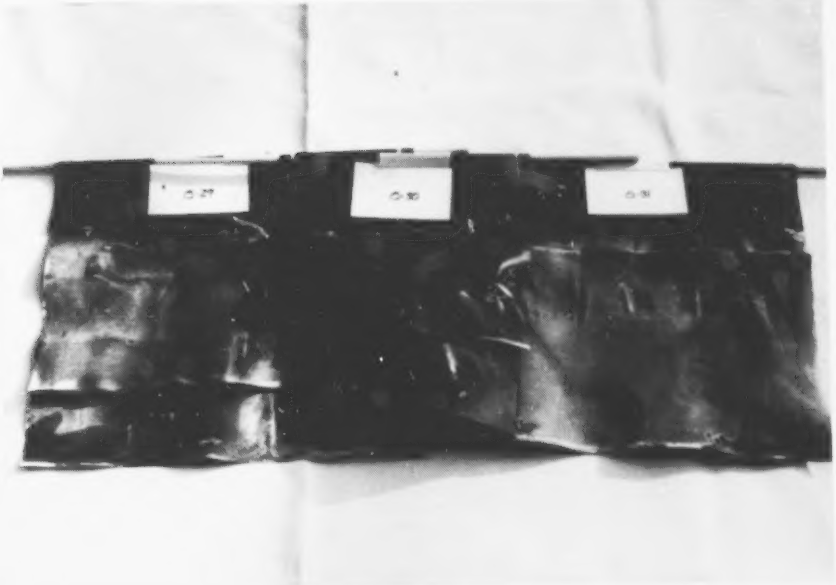


Figure 38. Appearance of CSPE Samples 23 (029) and 24 (031), and PVC/CPE Sample 16 (030) after 12 months in 10 percent sodium hydroxide.

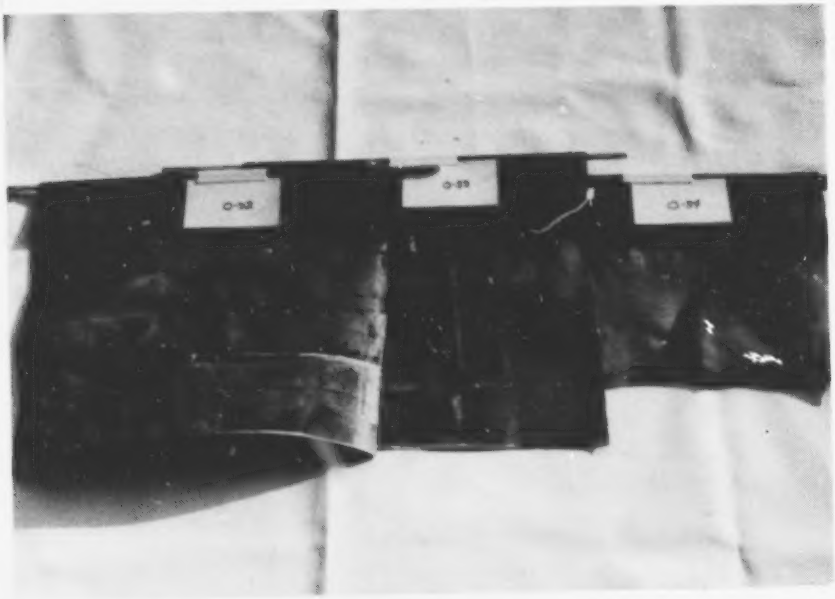


Figure 39. Appearance of CPE Samples 2 (032) and 18 (033) and CSPE Sample 25 (034) after 12 months in 10 percent sodium hydroxide.

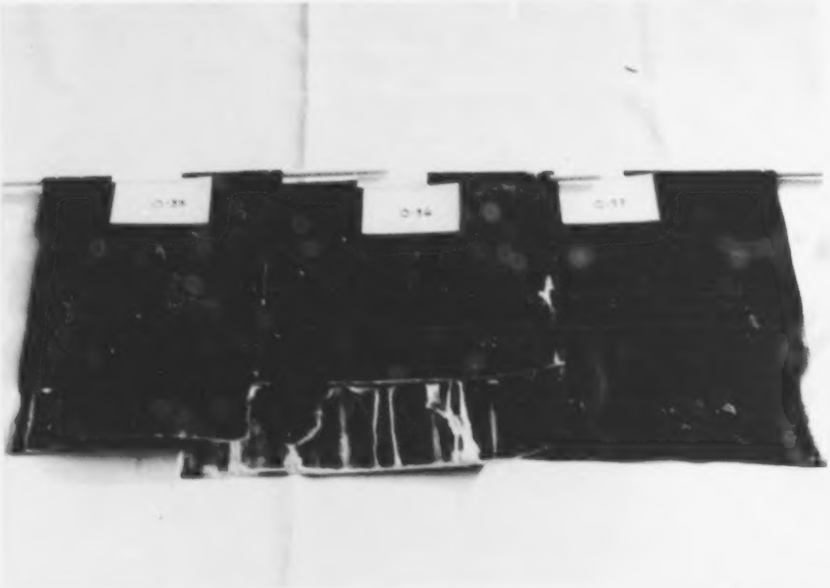


Figure 40. Appearance of PVC Sample 37 (035) and E1A Sample 9 (036) and 26 (037) after 12 months in 10 percent sodium hydroxide.

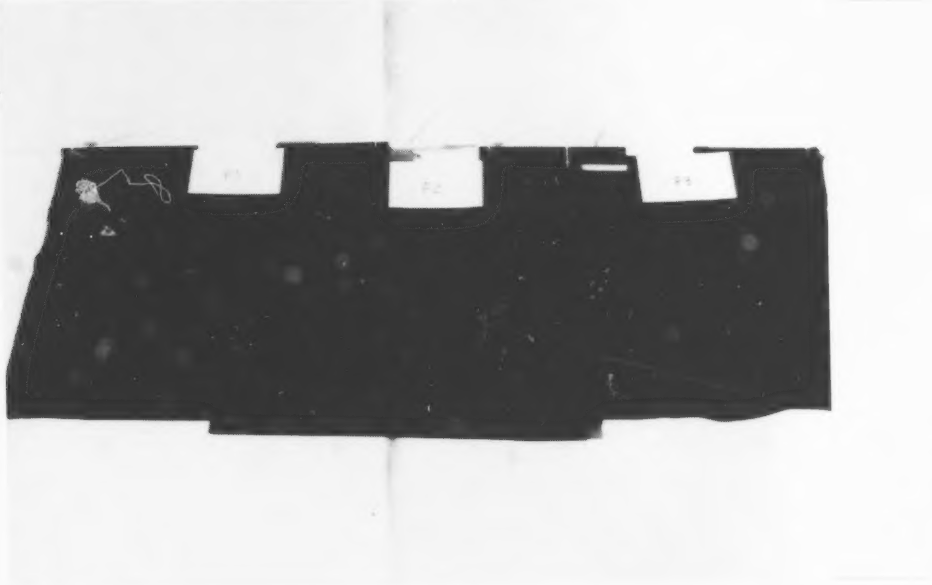


Figure 41. Appearance of CPE Sample 1 (P1) and CSPE Samples 6 (P2) and 22 (P3) after 12 months in 10 percent methyl ethyl ketone.

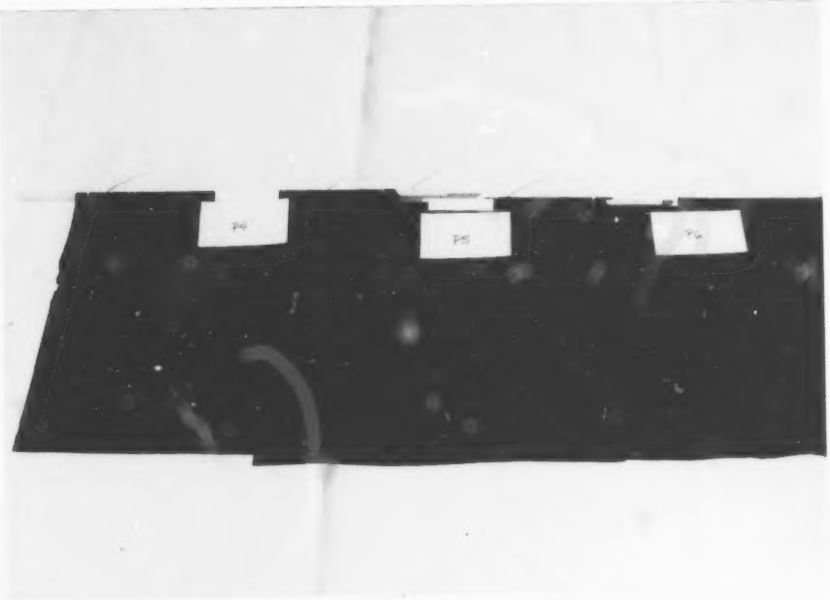


Figure 42. Appearance of CPE Sample 17 (P4), and CSPE Sample 3 (P5) and 19 (P6) after 12 months in 10 percent methyl ethyl ketone.

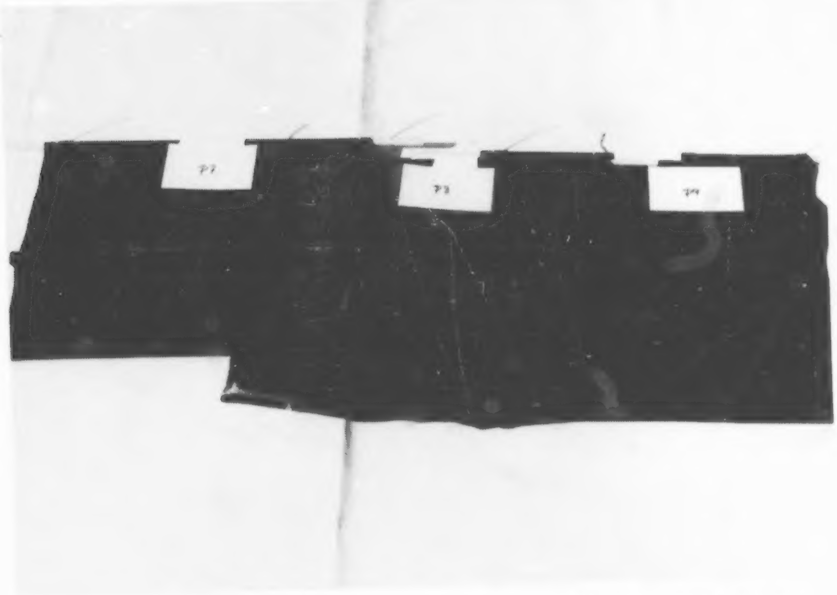


Figure 43. Appearance of CSPE Samples 4 (P7), 20 (P8) and 5 (P9) after 12 months in 10 percent methyl ethyl ketone.

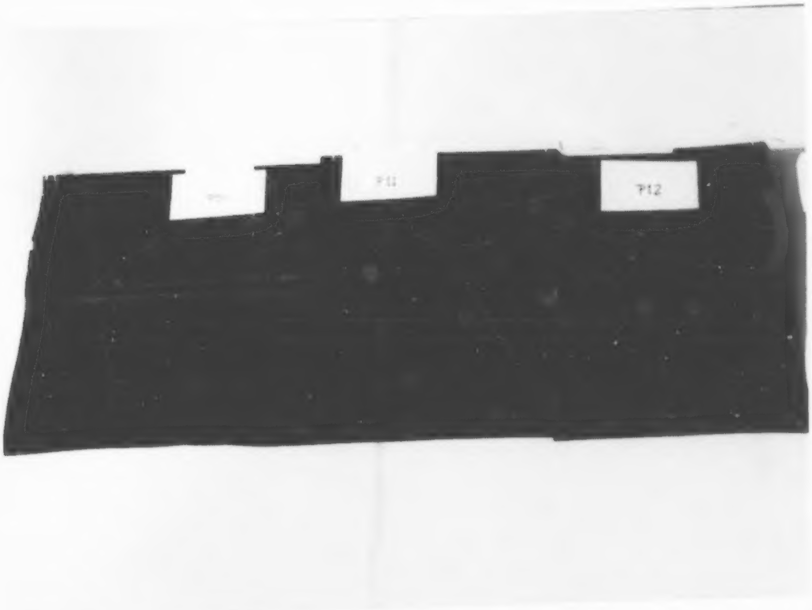


Figure 44. Appearance of CSPE Samples 21 (P10) and 34 (P12), and LLDPE Sample 13 (P11) after 12 months in 10 percent methyl ethyl ketone.

Reproduced from
best available copy.

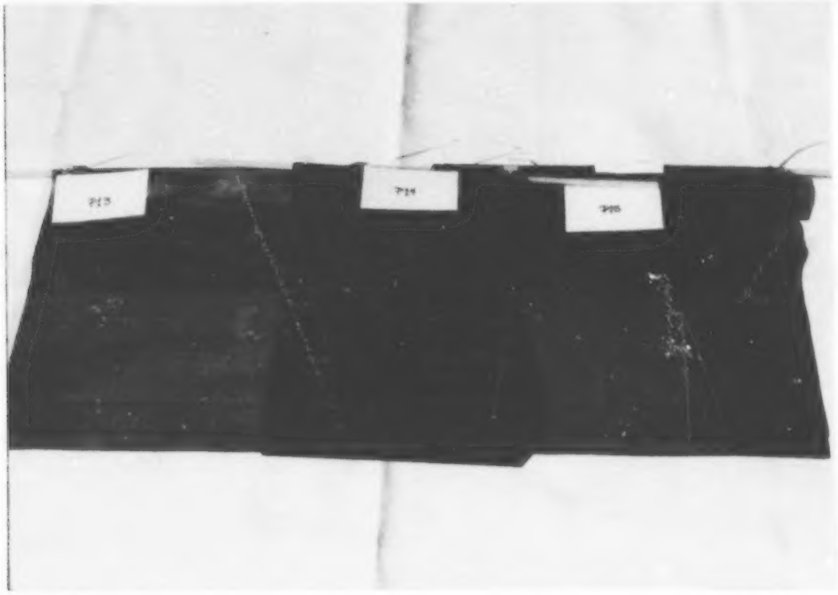


Figure 45. Appearance of EPDM Samples 10 (P13) and 27 (P15), and HDPE Sample 30 (P14) after 12 months in 10 percent methyl ethyl ketone.

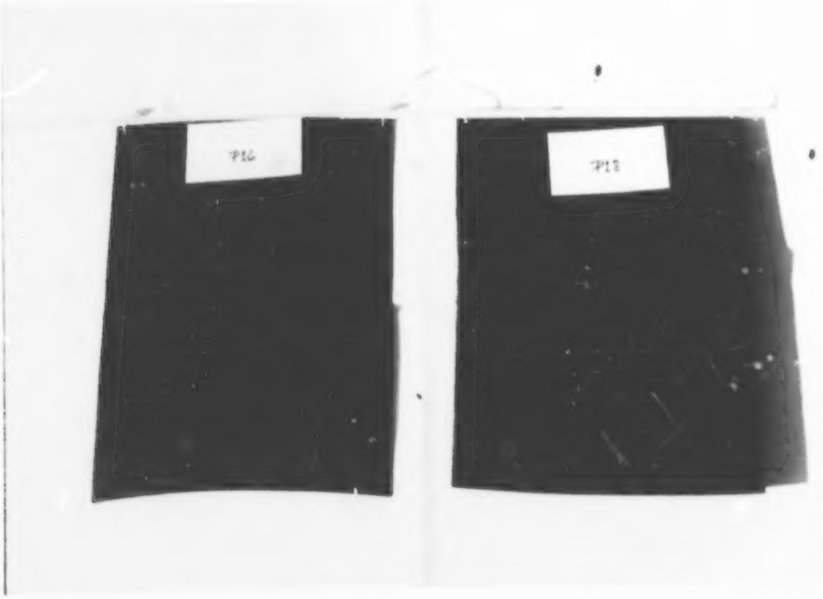


Figure 46. Appearance of HDPE Samples 31 (P16) and 32 (P18) after 12 months in 10 percent methyl ethyl ketone.

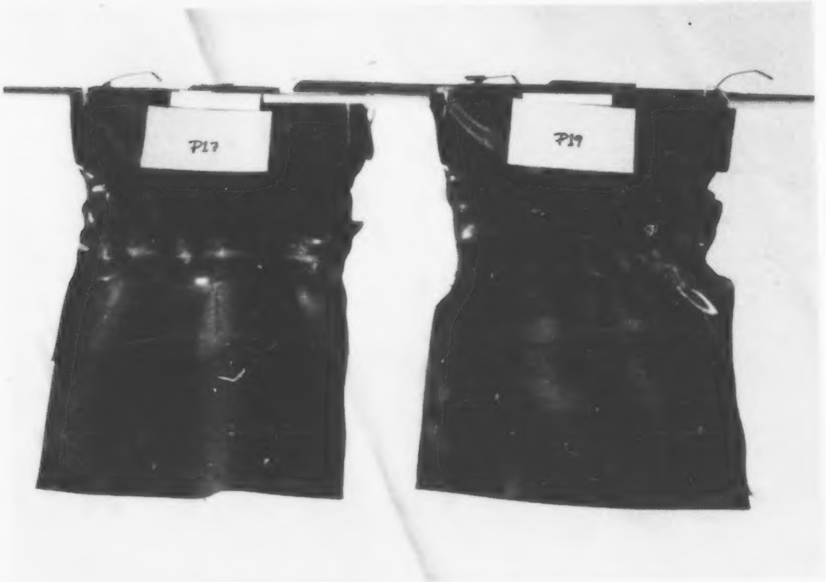


Figure 47. Appearance of PVC Samples 14 (P17) and 35 (P19) after 12 months in 10 percent methyl ethyl ketone.

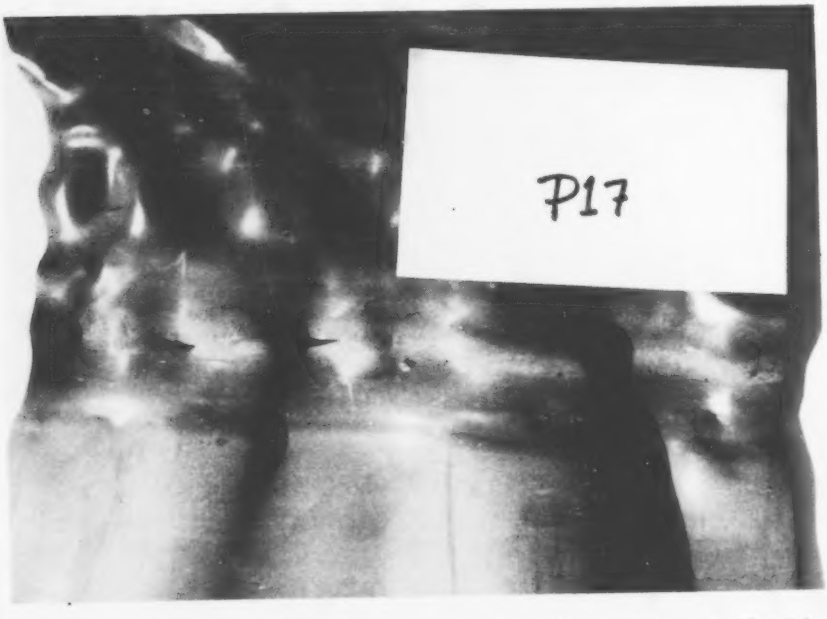


Figure 48. Close-up view of cracking in PVC Sample 14 (P17) after exposure to methyl ethyl ketone.

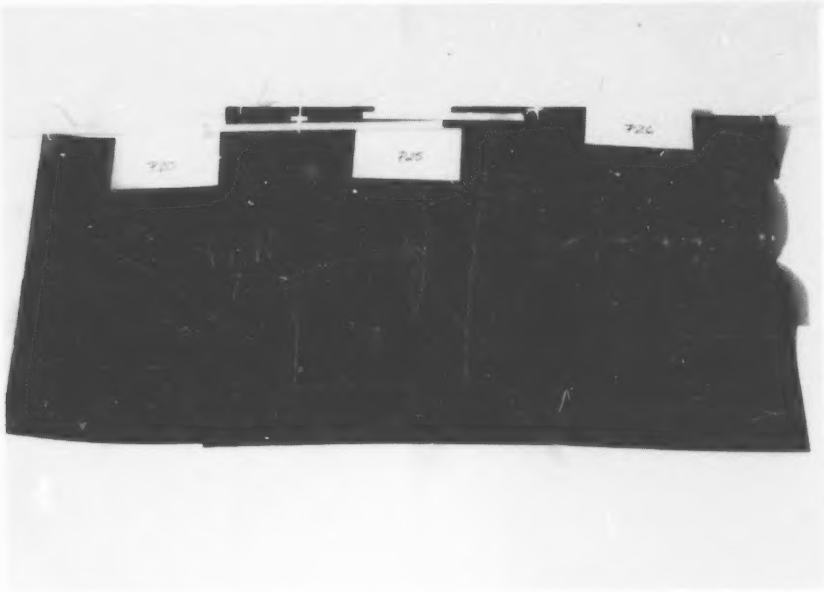


Figure 49. Appearance of HDPE Sample 33 (P20), CSPE Sample 8 (P25) and PVC Sample 15 (P26) after 12 months in 10 percent methyl ethyl ketone.

Figure 50. Blistering of CPE Samples 11 (P21) and 28 (P22) after 12 months in 10 percent methyl ethyl ketone.

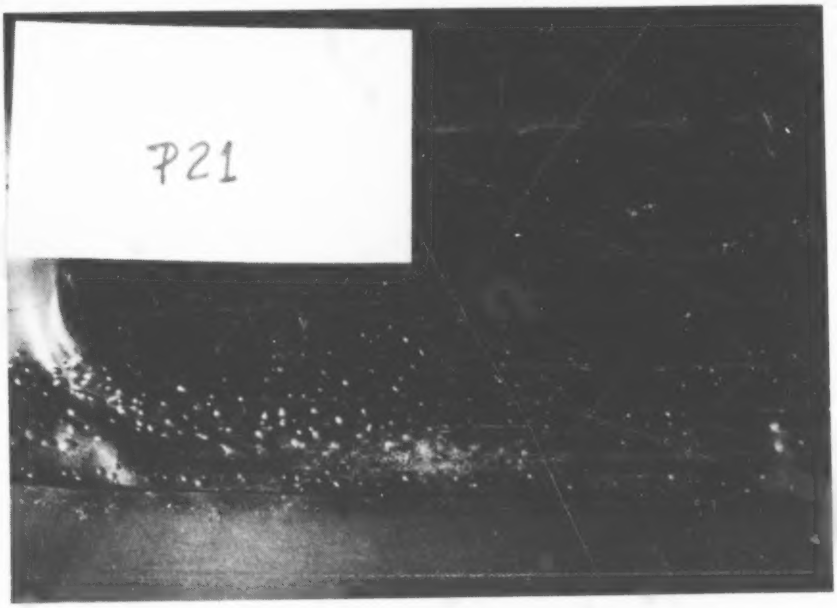


Figure 51. Close-up view of blistering of 30 mil CPE Sample 11 (P21).

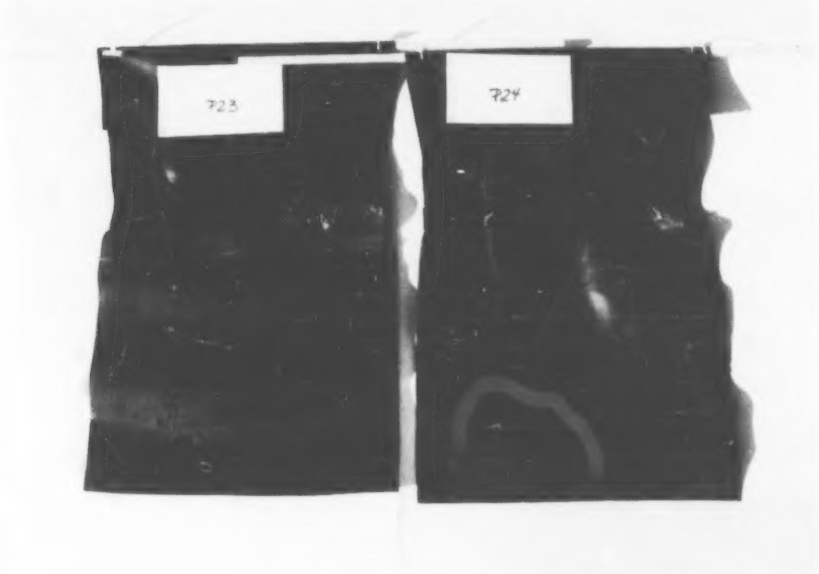


Figure 52. Appearance of CPE Samples 12 (P23) and 29 (P24) after 12 months in methyl ethyl ketone. Note blistering of the samples.

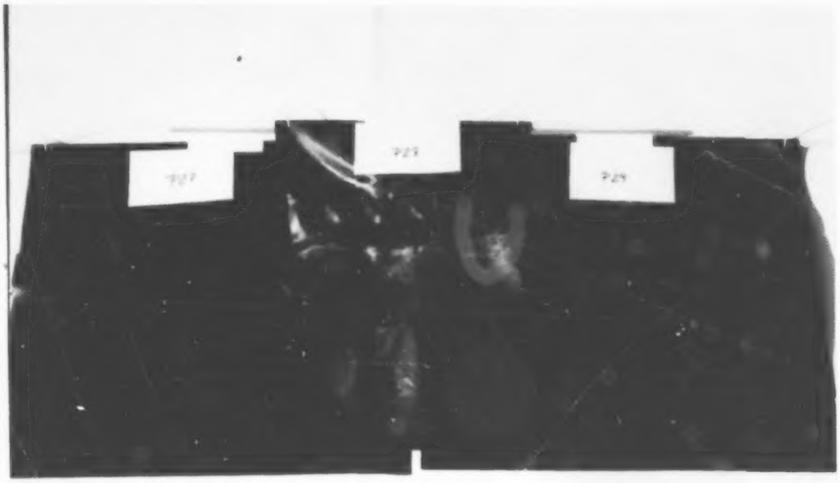


Figure 53. Appearance of CSPE Samples 7 (P27) and 23 (P29), and PVC Sample 36 (P28) after 12 months in 10 percent methyl ethyl ketone.

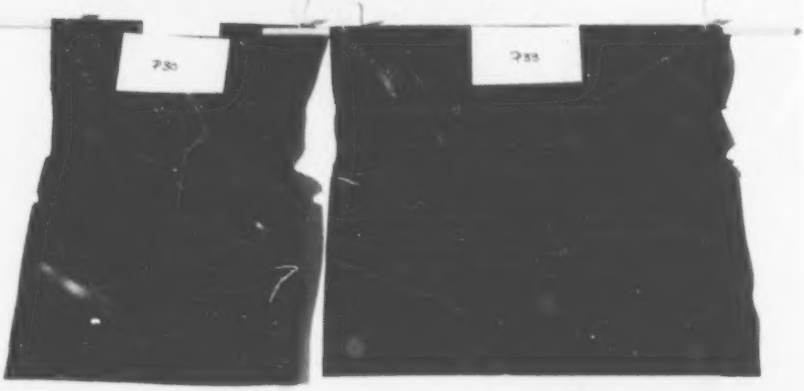


Figure 54. Appearance of PVC Sample 16 (P30) and CPE Sample 18 (P33) after 12 months in 10 percent methyl ethyl ketone.

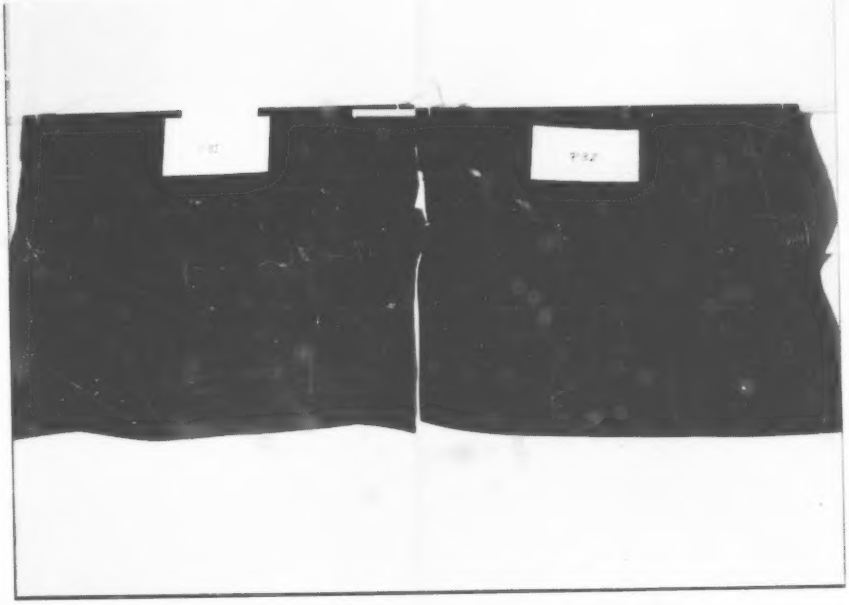


Figure 55. Appearance of CSPE Sample 24 (P31) and CPE Sample 2 (P32) after 12 months in 10 percent methyl ethyl ketone.

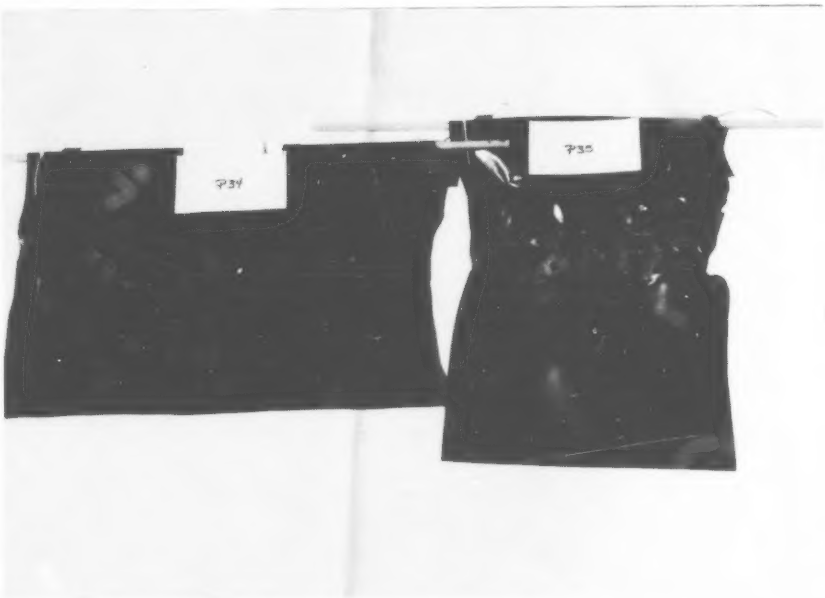


Figure 56. Appearance of CSPE Sample 25 (P34) and PVC Sample 37 (P35) after 12 months in 10 percent methyl ethyl ketone.

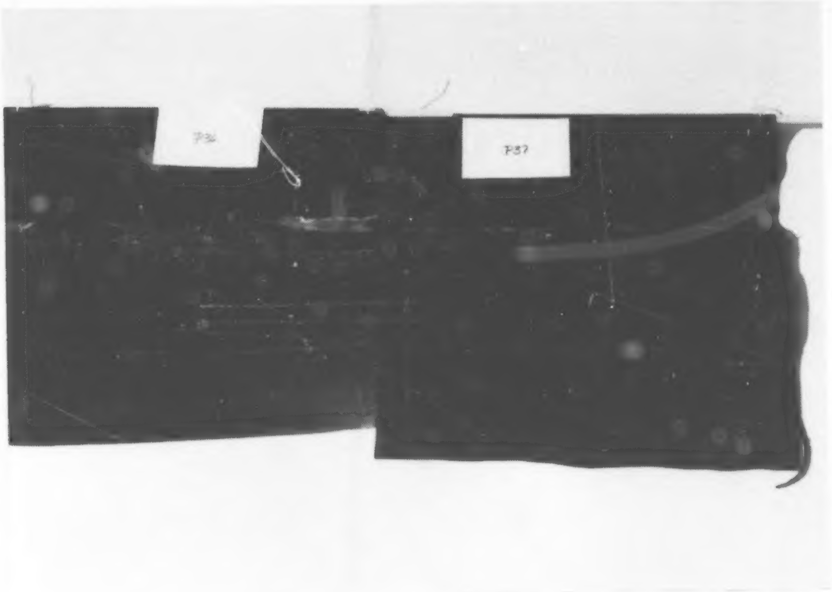


Figure 57. Appearance of E1A Samples 9 (P36) and 26 (P37) after 12 months in 10 percent methyl ethyl ketone. Note surface peeling of the material.

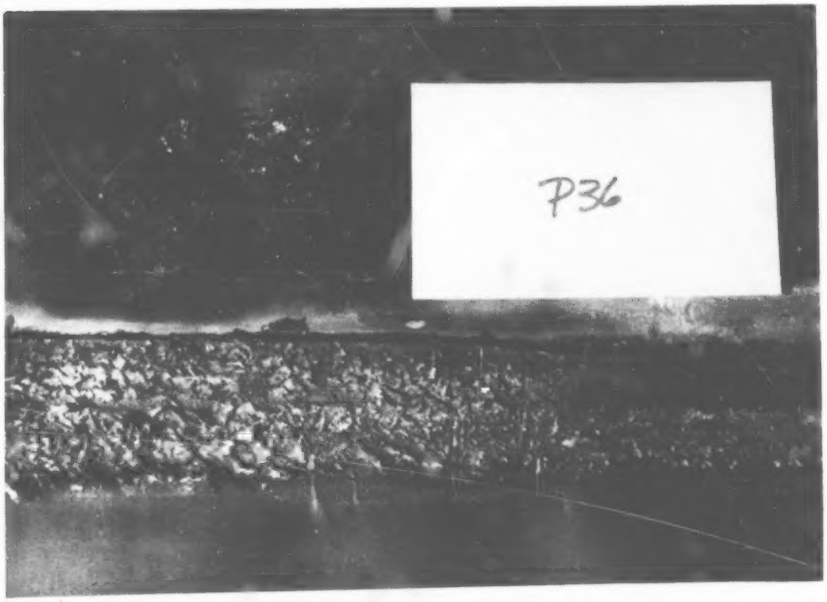


Figure 58. Close-up of surface peeling of E1A Sample 9 (P36).

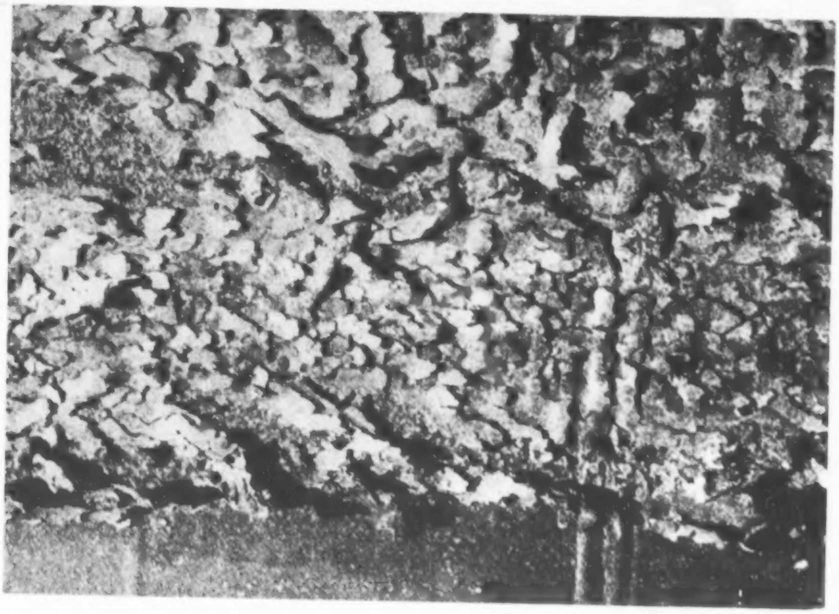


Figure 59. Magnified view of surface peeling of Sample 9.

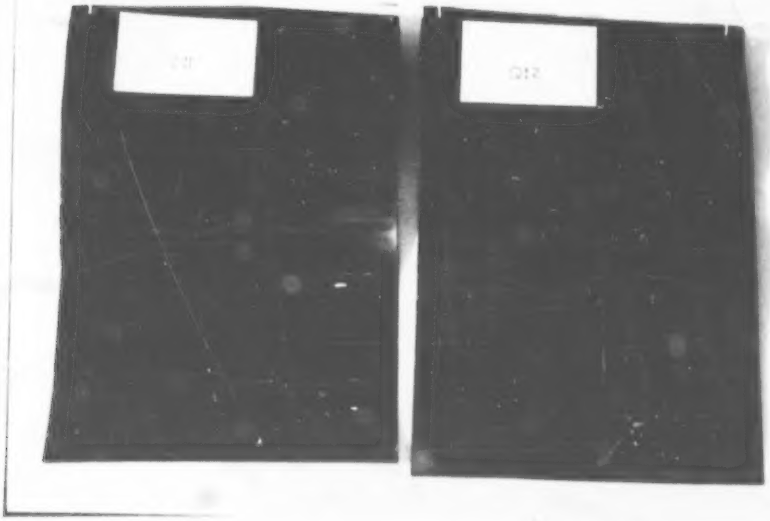


Figure 60. Appearance of LLDPE Samples 13 (Q11) and 34 (Q12) after 12 months in 100 percent methylene chloride.

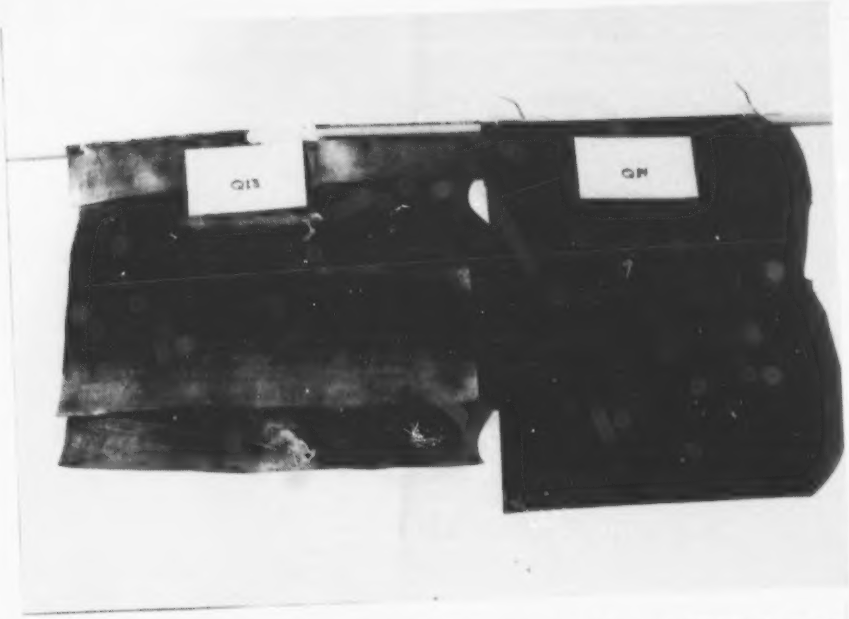


Figure 61. Appearance of EPDM Sample 10 (Q13) and HDPE Sample 30 (Q14) after 12 months in 100 percent methylene chloride.

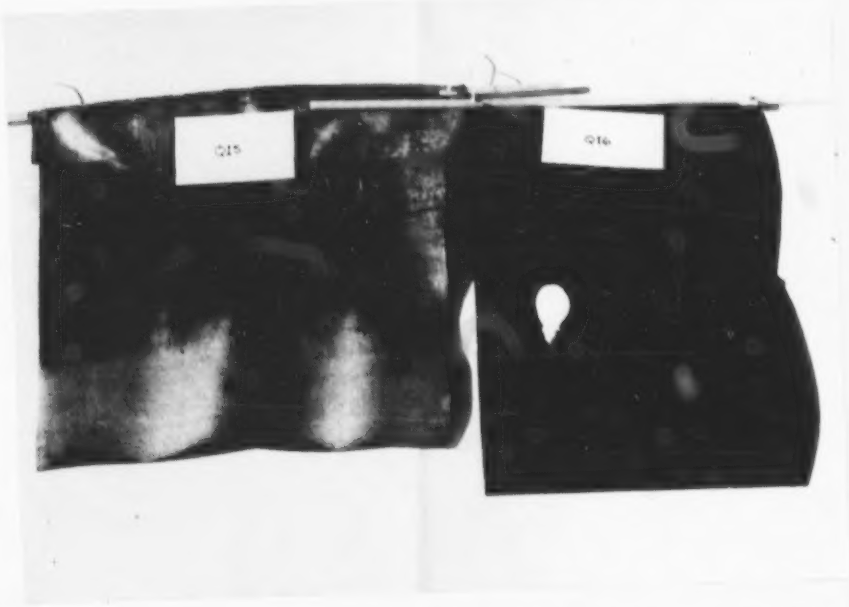


Figure 62. Appearance of EPDM Sample 27 (Q15) and HDPE Sample 31 (Q16) after 12 months in 100 percent methylene chloride.

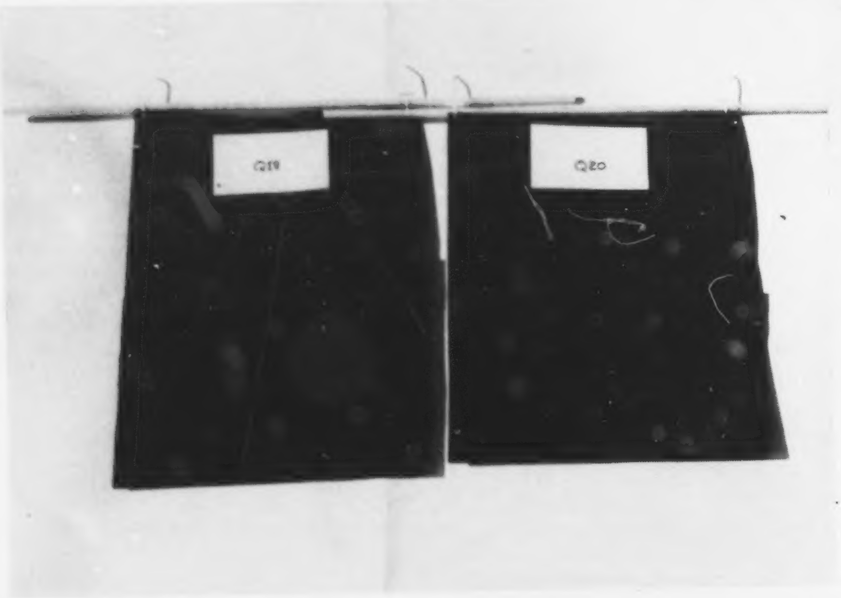


Figure 63. Appearance of HDPE Samples 32 (Q18) and 33 (Q20) after 12 months in 100 percent methylene chloride.

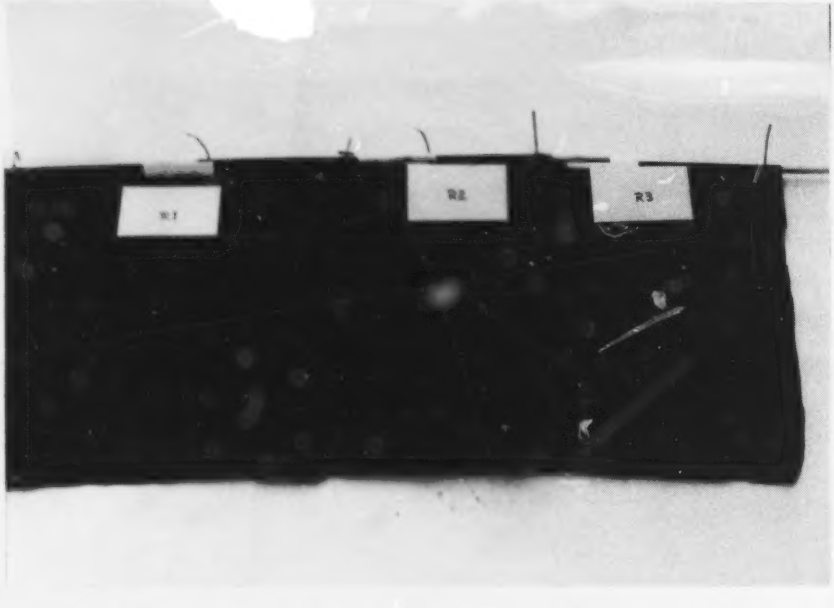


Figure 64. Appearance of CPE Sample 1 (R1), and CSPE Samples 6 (R2) and 22 (R3) after 12 months in 10 percent furfural

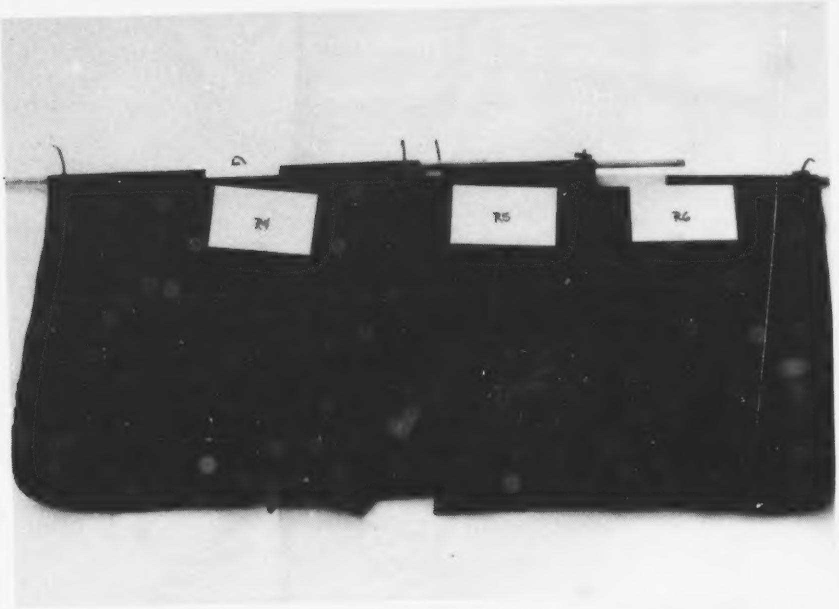


Figure 65. Appearance of CPE Sample 17 (R4), and CSPE Samples 3 (R5) and 19 (R6) after 12 months in 10 percent furfural.

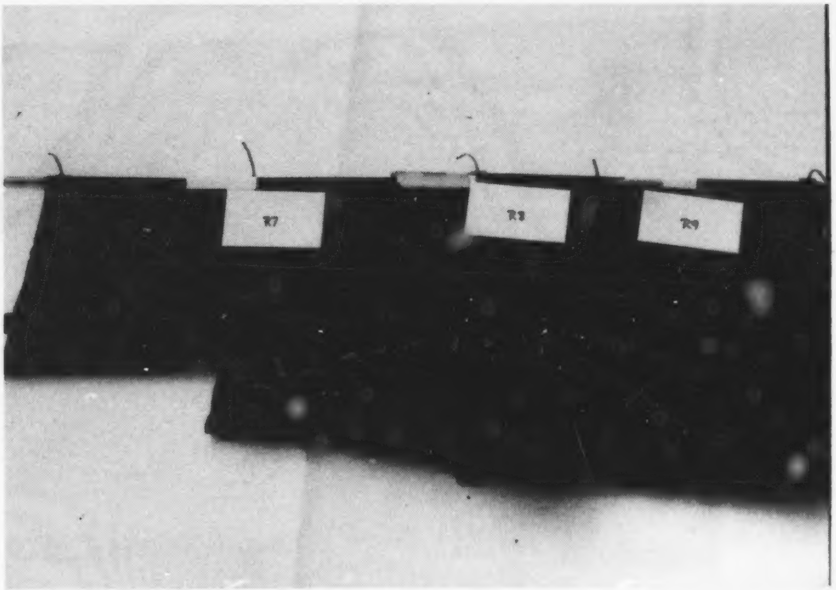


Figure 66. Appearance of CSPE Samples 4 (R7), 20 (R8) and 5 (R9) after 12 months in 10 percent furfural.

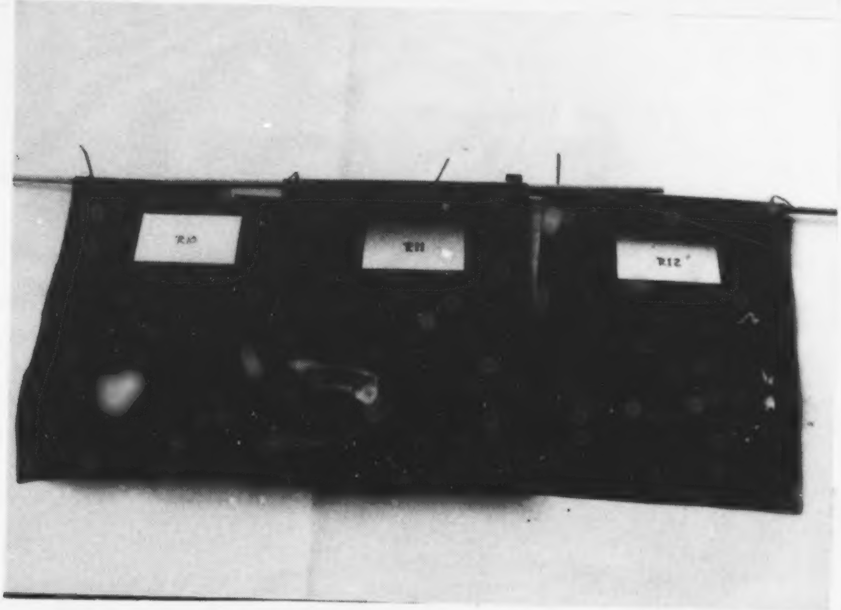


Figure 67. Appearance of CSPE Sample 21 (R10), and LLDPE Samples 13 (R11) and 34 (R12) after 12 months in 10 percent furfural.

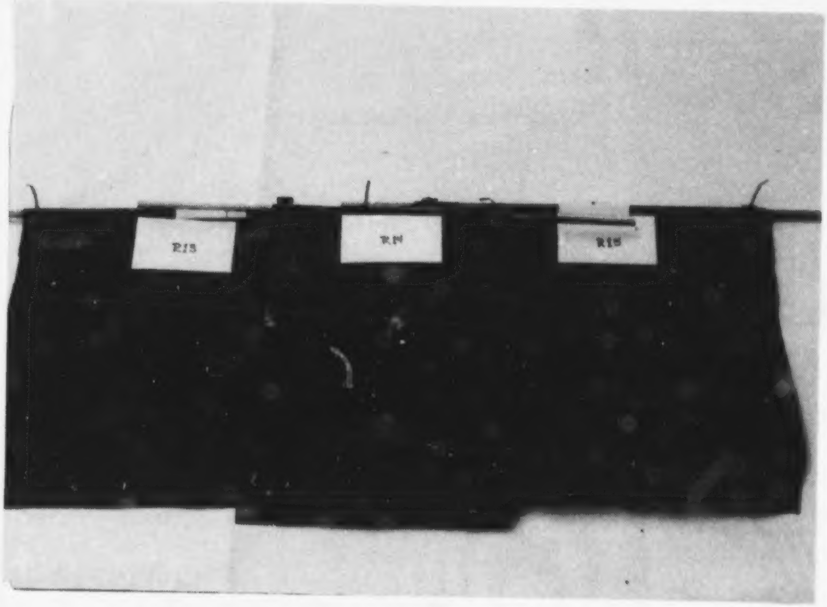


Figure 68. Appearance of EPDM Samples 10 (R13) and 27 (R15), and HDPE Sample 30 (R14) after 12 months in 10 percent furfural.

Reproduced from
best available copy.

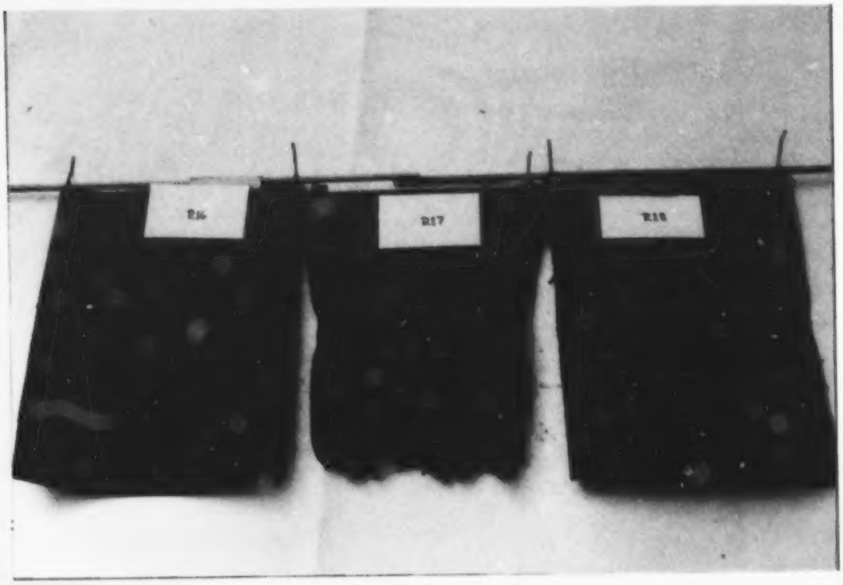


Figure 69. Appearance of HDPE Samples 31 (R16) and 32 (R18), and PVC Sample 14 (R17) after 12 months in 10 percent furfural. Some degradation has occurred to bottom edge of Sample 14.

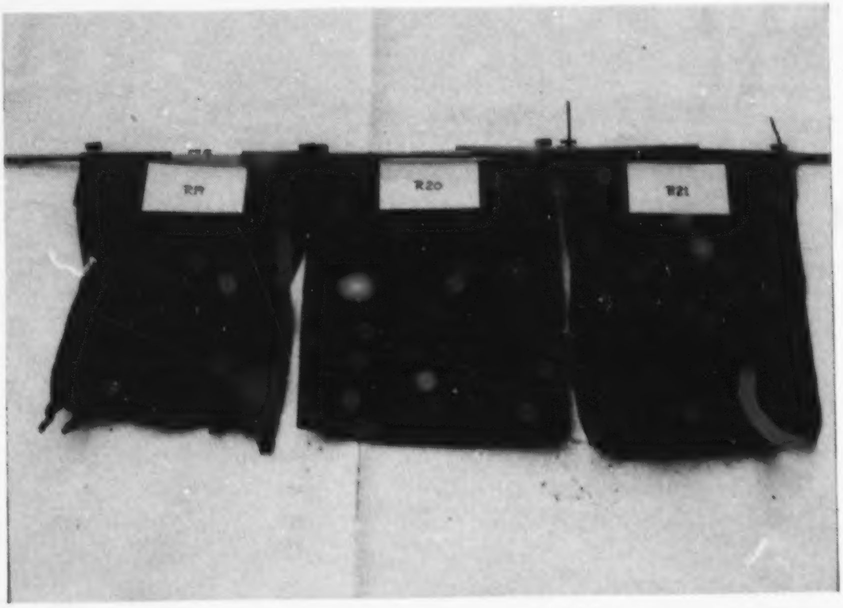


Figure 70. Appearance of PVC Sample 35 (R19), HDPE Sample 33 (R20), and CPE Sample 11 (R21) after 12 months in 10 percent furfural. Some degradation has occurred to bottom edges of Samples 35 and 11.

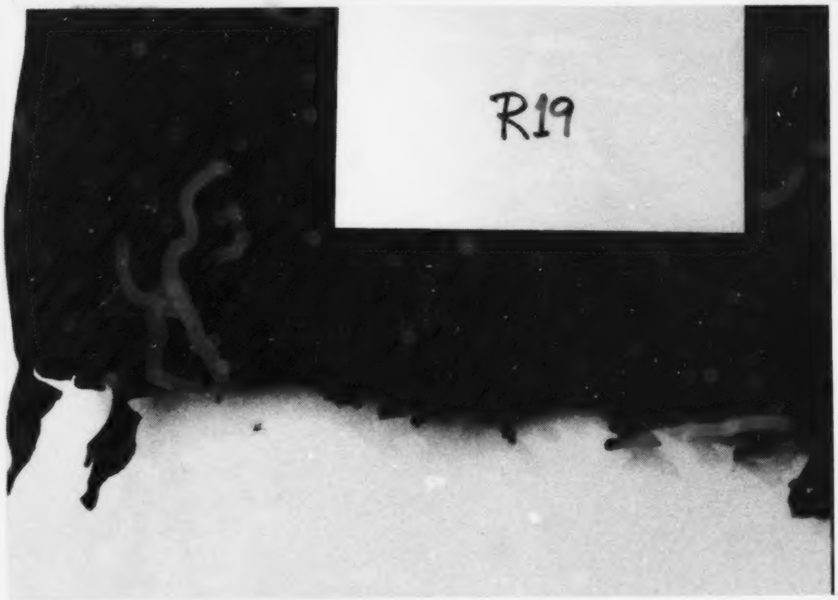


Figure 71. Close-up of PVC Sample 35.

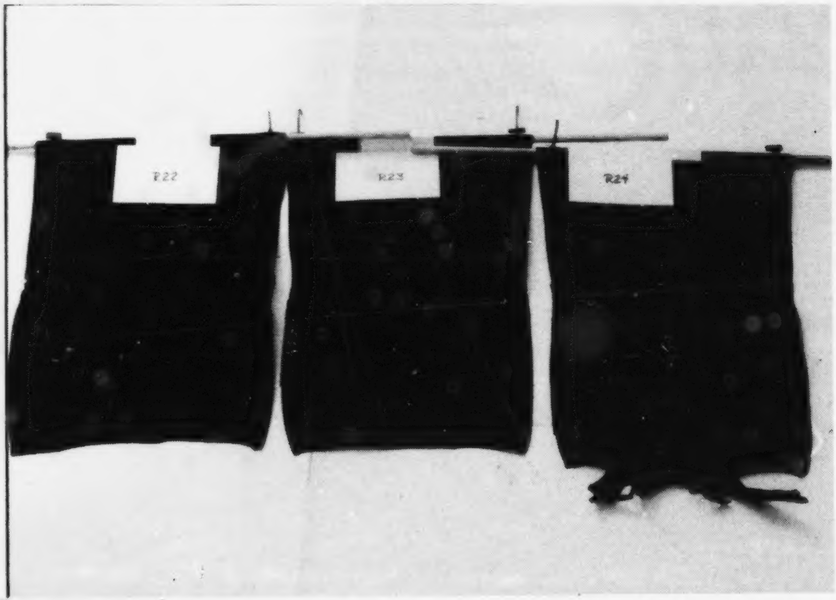


Figure 72. Appearance of CPE Samples 28 (R22), 12 (R23) and 29 (R24) after 12 months in 10 percent furfural. Some blistering has occurred to the materials.

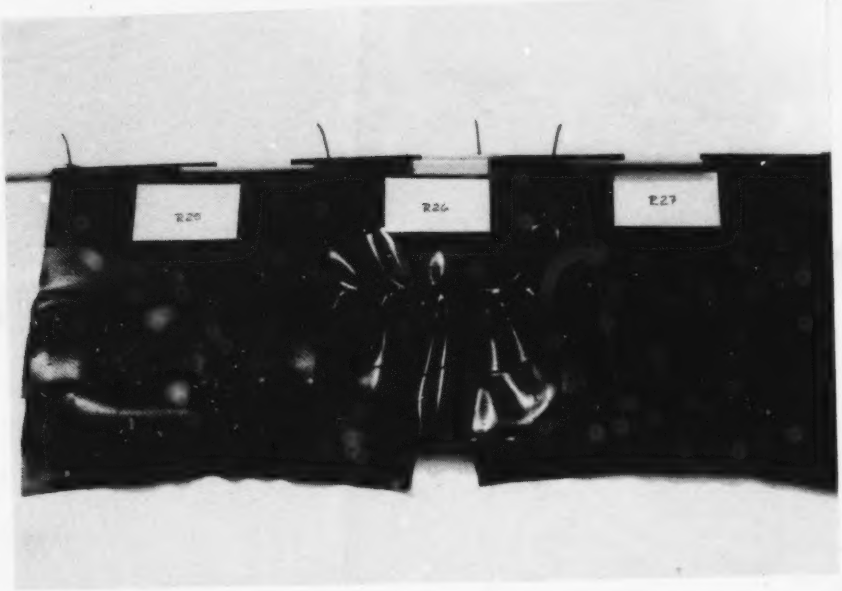


Figure 73. Appearance of CSPE Samples 8 (R25) and 7 (R27), and PVC Sample 15 (R26) after 12 months in 10 percent furfural.

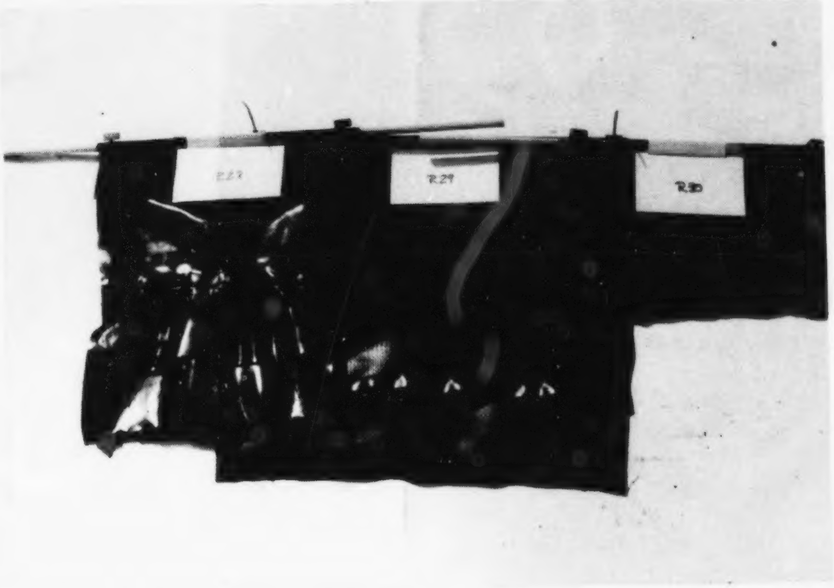


Figure 74. Appearance of PVC Samples 36 (R28) and 16 (R30), and CSPE Sample 23 (R29) after 12 months in 10 percent furfural. Sample 16 has been severely damaged by the chemical.

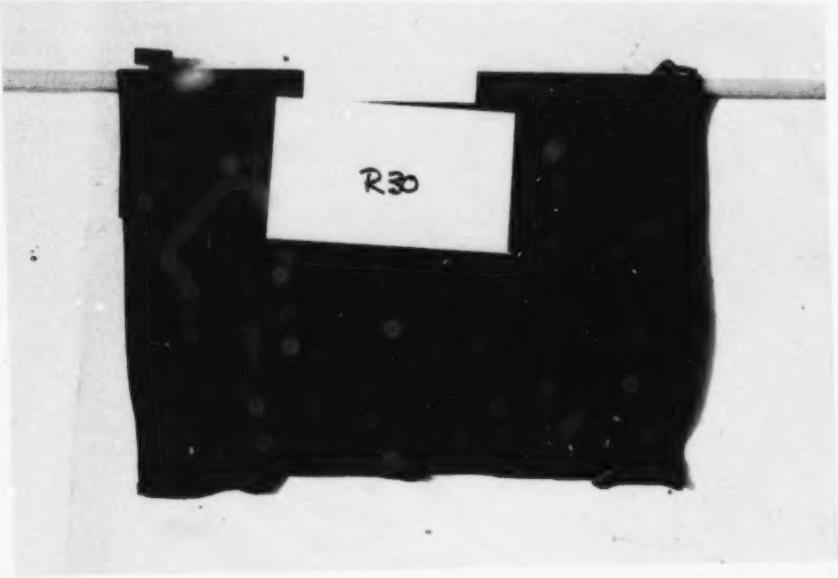


Figure 75. Close-up of damage to Sample 16.

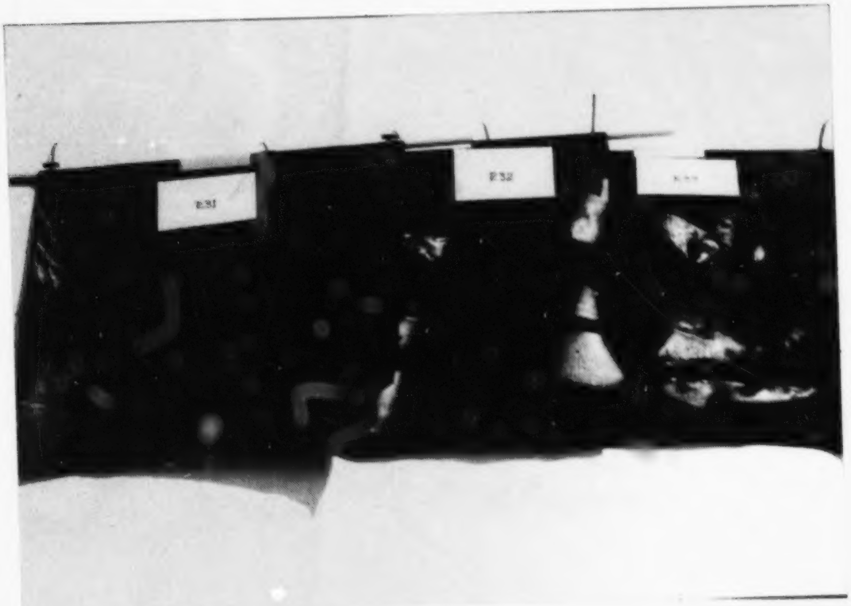


Figure 76. Appearance of CSPE Sample 24 (R31), and CPE Samples 2 (R32) and 18 (R33) after 12 months in 10 percent furfural. Some blistering has occurred to the CPE materials.

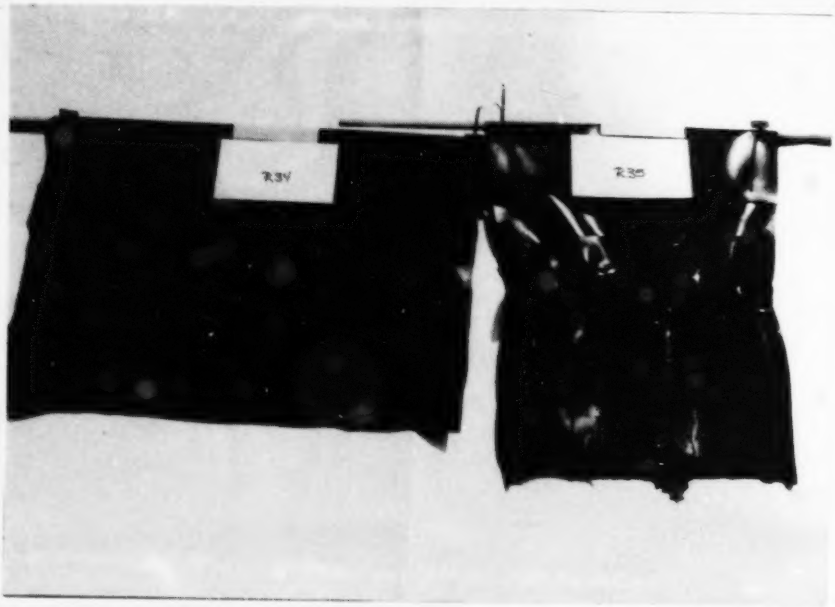


Figure 77. Appearance of CSPE Sample 25 (R34) and PVC Sample 37 (R35) after 12 months in 10 percent furfural.

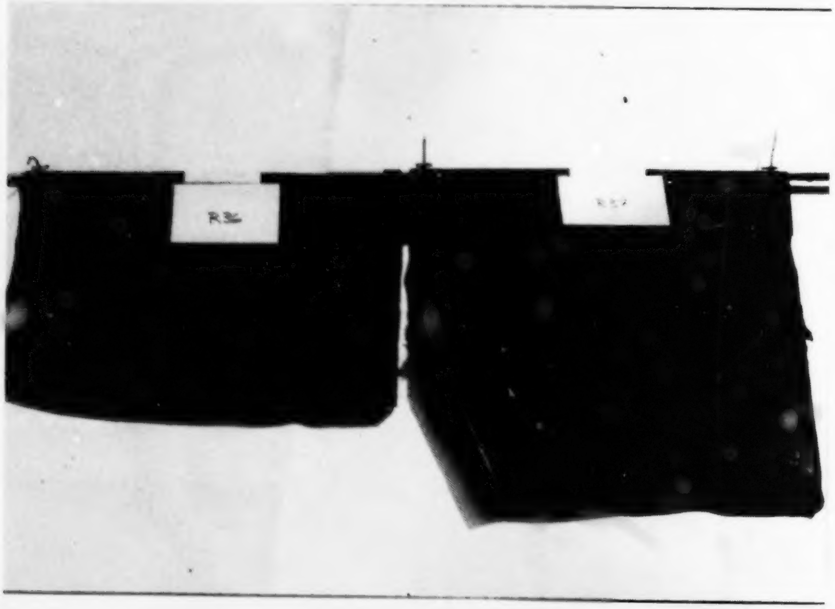


Figure 78. Appearance of E1A Samples 9 (R36) and 26 (R37) after 12 months in 10 percent furfural. Samples were severely damaged by the chemical.

Reproduced from
best available copy.

R36

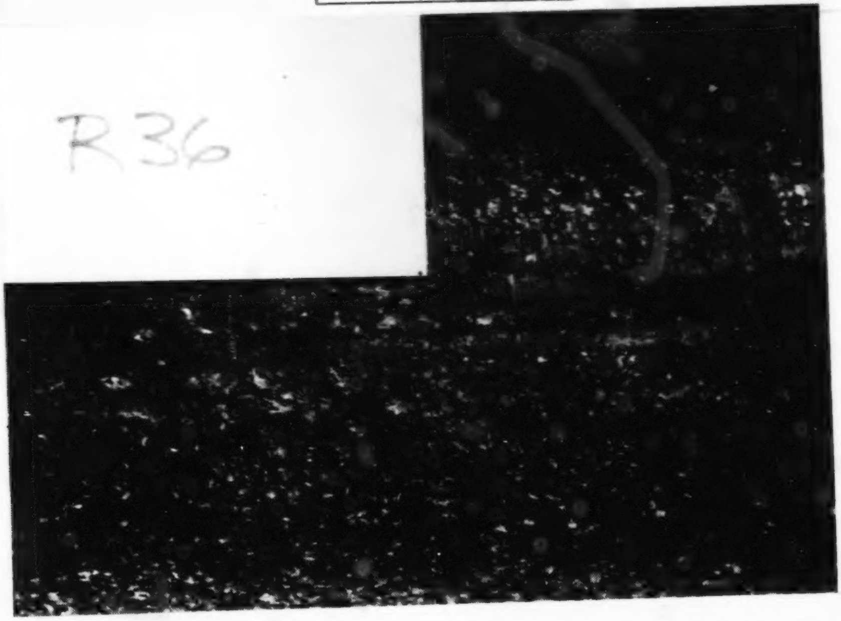


Figure 79. Close-up view of surface peeling of Sample 9.

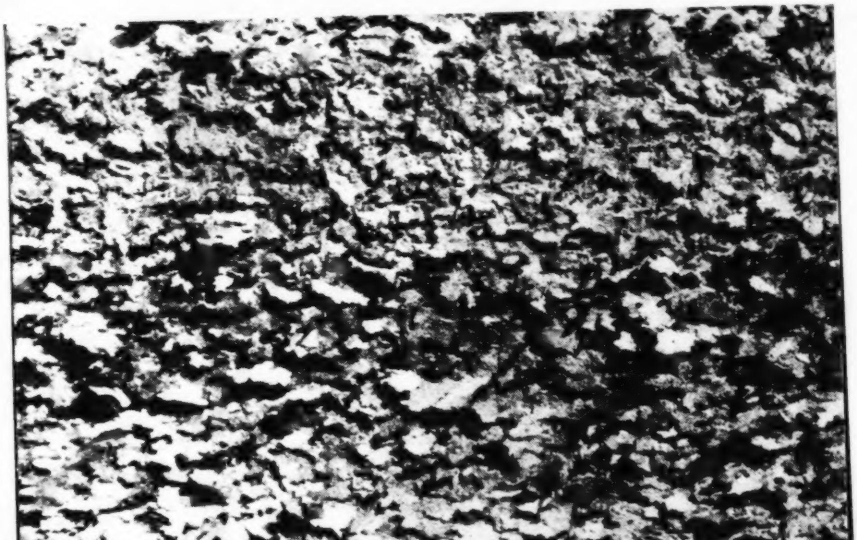


Figure 80. Magnified view of surface peeling of Sample 9.